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# TRANSLATION

SPACE (COLLECTION OF ARTICLES)

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## FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

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## FOREWORD

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# EDITED MACHINE TRANSLATION

SPACE (COLLECTION OF ARTICLES)

English Pages: 99



PREPARED BY:

TRANSLATION DIVISION
FOREIGN TECHNOLOGY DIVISION
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Huge successes in rocket technology allowed us to start flights in cosmic space beyond the limits of terrestrial atmosphere. In connection with this, wide circle of Soviet readers showed great interest in many questions connected with space: what goal exploration and mastering of cosmic space is pursuing, by what methods this is carried out, what are results of exploration, and in general, what constitutes the space and what may man, penetrating it, encounter. Purpose of prospective collection "Space" is to answer all these questions in popular form.

It is assumed that collection will be published twice a year. In collection concrete works carried out on space rockets and artificial earth satellites will be described, theoretical works will be published, and also survey articles on wide range of problems connected with penetration of man into cosmic space. Translations of certain works carried out abroad will be inserted. Content of articles of collection should be accessible to wide circle of readers not connected in their own work with science or technology. At the same time many articles will be read with interest by engineers and scientific workers, occupied with study of adjacent problems.

Editorial office will be glad to receive wishes of readers in connection with materials published in collection, and will endeavor in subsequent issues to consider them.

Responsible editor

Doctor of Physical and Mathematical Sciences

V. I. Krasovskiy

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# UNEDITED ROUGH DRAFT TRANSLATION

INTERSTELLAR FLIGHTS

BY: K. P. Stanyukovich and V. A. Bronshten

English Pages: 29

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PREPARED BY:

TRANSLATION DIVISION
FOREIGN TECHNOLOGY DIVISION
WP-AFB, OHIO.

# INTERSTELLAR FLIGHTS

K. P. Stanyukovich and V. A. Bronshten

After the remarkable flights of Soviet space rockets to the moon and Venus, after the launching of the automatic interplanetary station Mars-1, and after the triumphal flights of Soviet cosmonauts around the earth, no one can doubt that the nearest planets, Venus and Mars, will be reached in the near future. This accomplishment may be made even with liquid-fuel rockets.

Reaching the more distant planets, Jupiter, Saturn, Uranus, Neptune, and Pluto, will be more difficult. Indeed, it is 6 billion kilometers to Pluto! This is 40 times greater than the distance from the earth to the sun and 80 times longer than the parabolic flight trajectory to Mars. A rocket, launched on such a trajectory with an initial velocity of 16.7 km/sec will reach Mars in 70 days but will take 19 years or more to reach Pluto. It is, nevertheless, possible to reach these planets.

The use of atomic and ion rockets holds wide prospects for increasing velocity and shortening the flight time to the distant planets. In order to attain a high velocity the rocket must discharge a portion of its mass with the highest possible velocity in the reverse

direction. Chemical rockets discharge the products of propellant combustion, while atomic rockets discharge an inner mass which has been heated to high temperature, while ion rockets use charged particles (ions) which are dispersed by powerful accelerators.

But is it possible to fly beyond the limits of the solar system, to stars some of which are surely surrounded by their own planetary systems?

## Dimensions of Space

How great is the distance to a star? Even the closest star, Proxima in the constellation Centauri is so distant that a ray of light traveling at a speed of 300,000 cm/sec takes $4^1/_3$ years to reach us. Indeed, it takes 8 min 18 sec for light to reach us from the sun. This means that the nearest star is 270,000 times further from the earth than the sun and 7,000 times further than Pluto, the most distant planet of the solar system.

Stellar distances are so great that they cannot be measured even in billions of kilometers. It is 40,000 billion kilometers to Proxima Centauri. The disadvantage of using such numbers has lead to the introduction into stellar astronomy of new units of linear measure. One of these is the light year which is the distance traveled by light in a period of one year. Thus we say that it is $4^1/_3$ light years to Proxima Centauri, 9 light years to Sirius and 27 light years to Vega.

But these are only our nearest neighbors in space. The star Betelgeuse is 300 light years away, Polaris — 600 light years, Zeta Aurigae — 980, the stellar cluster in Perseus — 4,300, and the globular star cluster in Hercules — 34,000 light years. And yet all of these stars and star clusters are located within our stellar system the

Milky Way (Galaxy).

Are other galaxies far away? The galaxy in the constellation Andromeda, often referred to as the Andromeda Nebula, is 1,500,000 light-years distance from us. Distances to other galaxies within observable range amount to from several millions to 6 billion light years. But we will not go that far. For now we will limit our task to reaching just the closest stars. Is it possible?

## The Photon Rocket

If we were to set out for Proxima Centauri in a "typical" interplanetary rocket it would take hundreds of thousands of years. Even the use of an atomic or ion rocket would not permit us to accomplish an interstellar round-trip flight within an acceptable period of time. The duration of human life limits possible flight time to several years or at best to several decades.

Obviously, in order to reach other galaxies velocities close to the speed of light are necessary. Is there any principle known to science which will permit imparting such velocities to a rocket? Yes, such a principle is known, the so-called photon rocket.

In the photon rocket a flow of photons (particles of light which, as is known, are material) provides the reactive acceleration instead of a gas. The phenomena of light pressure, experimentally demonstrated by the Russian physicist P. N. Lebedev in 1901, serves as an illustration. Any electromagnetic radiation (in particular, light) consists of separate "bundles" or quanta of energy, each of which has a definite mass. These "particles" of light are called photons. The physicist showed that it is possible to convert other elementary particles of matter (e.g., the electron and proton, by means of their combination) into photons. This process is called annihilation.

The electron, as we know, is an elementary particle of matter which enters into the composition of an atom and has a negative charge. Positively charged particles found in the atomic nucleus whose mass exceeds that of the electron by 1800 orders of magnitude, are called protons. Protons and electrons are found in all bodies and substances, in the atoms of all chemical elements.

In addition to these particles, modern physics has discovered other, rarely encountered particles, in particular the positron which has the mass of an electron but is charged positively, and the antiproton which has the mass of a proton but is charged negatively. Antiprotons, positrons and certain other "antiparticles" make up what is called antimatter which differs from ordinary matter in the sign of charge and the direction of rotation (spin) of its elementary particles. When particles of antimatter are combined with the same particles of matter, photons are formed.

The idea of the photon rocket (Fig. 1) centers around reserves of matter and antimatter stored in special tanks which are speeded up by the accelerators to a point where they collide with each other and are converted into a stream of photons. The annihilation point is located at the focus of a gigantic parabolic mirror which directs the photons in powerful parallel rays at a velocity of 300,000 km/sec.

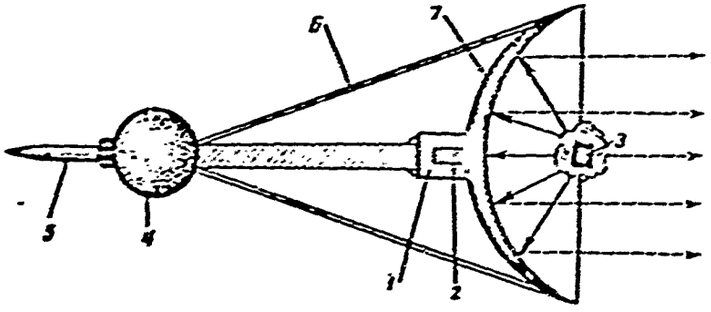


Fig. 1. Photon rockets. 1) supply of matter; 2) supply of antimatter; 3) point of combination between particles of matter and antimatter; 4) basic, large rocket; 5) small rocket; 6) brace; 7) mirror.

However, the realization of this project is beset with large obstacles. Positrons and antiprotons cannot yet be obtained in large numbers, let alone be protected from collision with the much more naturally prevalent electrons and protons. Even if this were accomplished, the mirror must reflect almost 100% of the photons without absorbing more than one million of a per cent, otherwise it would be so strongly heated that it would be melted and vaporized. For the same reason the walls of the chamber in which the beam of photons is to be formed, must be absolutely transparent. The rocket must be very large in order to protect the crew from harmful radiation and high temperatures generated in the photon engine. Thus, the technical problems of photon rocket construction are not yet solved.

Of course, it [illegible] possible to mention several ways of solving the difficulties described. Thus, particles and antiparticles might be obtained, using powerful magnetic fields. In addition to photons, mesons would be formed during reaction which would disperse with a velocity less than the speed of light, removing a portion of the energy.* Nevertheless, the efficiency of the photon rocket would be much higher than for any other [illegible].

Science and technology move ahead very fast. Just half a century ago Tsiolkovsky outlined the principles of the chemical propellant rocket and it has already become a reality. And it can be imagined that in another 50 years that which is still known only in principle may become a practical reality.

How will a flight to a star system be carried out with a photon rocket? During the first part of its flight the rocket will accelerate,

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* During annihilation, there are formed $\pi$-mesons which, after $2.5 \cdot 10^{-8}$ sec decay into $\mu^{\pm}$—mesons. In turn, after $2.10^{-6}$ sec these mesons decay to $\beta^{\pm}$—radiation and to neutrinos. The mean free path of mesons is about 500 meters.

gradually picking up speed. If we attribute to it an acceleration equal to the acceleration due to gravity on the earth, in 17 months the rocket will attain a velocity of 250,000 km/sec ($^5/_6$ speed of light). During this first period of flight the rocket covers a distance of 7,300 billion kilometers which is 120 times greater than the orbit radius of Pluto but only 13% of the distance to Proxima Centauri.

The second portion of the flight may be accomplished with the engine off at a constant inertial velocity. Such a flight takes 3 years and 4 months. Finally, the third portion of the flight (deceleration stage) is equal to the first both in length and in duration. The total duration of a flight such as the one given in our example, is 6 years and 3 months. The same period of time is required for the return trip. During a flight at such velocities, future cosmonauts will encounter a new and, at first glance, u...pected phenomenon. The journey which we have described takes (allowing one year's stay in the planetary system of Proxima Centauri) $13^1/_2$ earth years. But if the travelers accurately tabulate the days according to a clock on the rocket (the succession of day and night will, of course, not occur in the rocket) they will discover upon returning to the earth that only 9 years and 3 months have passed according to their clock. Where have the 4 odd years gone to? The answer to this question is given by the theory of relativity.

## Voyage in Time

More than 60 years ago the famous English writer Herbert Wells wrote a fantasy novel about a machine which permitted making voyages into the past and future. Wells did not know that 10 years after the publication of his book the German physicist Einstein would publish his general theory of relativity, one consequence of which is the

theoretical possibility of voyaging into the future using an interstellar rocket.

What is the theory of relativity? It is a scientific theory with which Einstein, in 1905, for the first time succeeded in explaining, from a single point of view, a number of observable phenomena which could not be explained on the basis of the physical laws known at that time. The range of these phenomena is very wide, covering mechanical motion (rectilinear or accelerated), propagation of electromagnetic waves (in particular light), and mass-energy relationships.

Let us begin with a simple example. Suppose we are traveling in an automobile along a straight highway and at some moment we find ourselves exactly midway between two targets located on the highway. At this moment two riflemen fire at the targets, one toward the front and the other toward the rear. It is clear that according to the law of combined velocities the forward target will be struck slightly sooner than the one in the rear since in the first case the velocity of the car is added to the velocity of the bullet and in the second case is subtracted from it. Thus, velocity is relative. Relative to the car (within the frame of reference of the moving automobile) the velocities of two bullets are the same but with respect to the ground (in a stationary frame of reference) they are different. Let us keep this example in mind.

Now let us imagine a binary star, a star satellite revolving around a main star and therefore now approaching the earth, then receding from it. In the process it gives off light which is propagated with a final, not instantaneous, velocity of 300,000 km/sec. If the speed of the star along its orbit is 30 km/sec (as is the earth's), the speed of the light and of the light source itself (i.e., the star) it would seem, must add when the motion is toward us, and subtract

when the motion is away from us. But then a light wave traveling at a rate of 300,030 km/sec may, after several decades or centuries, overtake a wave having a speed of 299,970 km/sec which was previously emitted by the star, before it has traveled from the star to the earth. Both waves arrive simultaneously and we see the star simultaneously in two positions. In reality nothing of the sort is observed.

Comparing the results of various physical experiments, Einstein came to the conclusion that the velocity of light is independent of the velocity of the light source and is not combined with it. The velocity of light in space is a maximal; no body or particle can travel faster than light.

The special theory of relativity postulates that physical laws are the same in all coordinate systems which move rectilinearly and uniformly with respect to each other (inertial systems) and that the velocity of light always has the same value in any inertial frame of reference.

The development of these assumptions (postulates) led Einstein to new laws of velocity addition, according to which no matter how we increase the velocity by adding a new velocity to it, we never exceed the speed of light. It became clear that the scales of distance and time interval are different in different frames of reference as it was with the velocities of the bullets in our example.

In previous mechanical relationships the conversion from the coordinate $x$ and time $t$ in a stationary frame of reference (earth) to the coordinate x' and time t' in an inertial reference system moving with respect to the earth (a rocket) looked like ($v$ being the rate of motion):

$$x = x' + vt, \qquad t = t'.$$

These relationships are called Galilean transformations. New mechanical relationships which have replaced the former, were introduced by Lorentz and then made simpler and more conclusive by Einstein. It turns out that if one takes into account the postulates formulated above, the law for coordinate and velocity conversion in the new mechanics will be described by the relationships (called Lorentz transformations):

$$x = \frac{x' + vt'}{\sqrt{1 - \frac{v^2}{c^2}}}, \qquad t = \frac{t' + \frac{v}{c^2}x'}{\sqrt{1 - \frac{v^2}{c^2}}},$$

where c is the velocity of light.

Obviously if velocity v is many times lower than the speed of light the denominator in the Lorentz transformation formulas will be equal to one and they are converted to the earlier Galilean transformations.

Relativity theory has not only explained but also predicted a number of phenomena which were soon discovered by means of astronomy and physics. Now there can be no doubt as to its correctness. The laws of classical physics represent special cases of the laws of relativity theory. One of the consequences of relativity theory is the phenomena of the slowing of time which is encountered by the passengers of a stellar flight.

To date there are numerous experimental verifications of this phenomenon.

Together with cosmic rays, a continuous flow of various particles reaches the earth. When they encounter nuclei of atoms in the air a definite kind of elementary particles, so-called mesons and hyperons, are often produced. These particles are very unstable. In an imperceptibly small interval of time they disintegrate to form other

elementary particles. Scientists have established their life at $10^{-6}$ sec. During this time the particles may traverse a very short path and yet some of them penetrate to the very surface of the earth.

What is the secret of such a life span of particles traveling swiftly through the atmosphere compared to those observed by scientists in the laboratory?

The secret is that their velocity is very close to that of light. An imaginary clock placed on one of these particles runs for just as long as that particle "lives," no more and no less. Time passes more slowly for this clock than it does for us as outside observers. According to our clock a much greater period of time has elapsed and the particle has traversed a gigantic distance during this time.

Recently the so-called Mossbauer effect was discovered which led to the observation of the fact that in hot gases where atoms travel at colossal speeds the wavelength of the spectral lines emitted by the gas shift toward the red end. In other words, the frequency of emitted electromagnetic waves decreases if the atoms travel at a very high velocity. This means that in such an atom the progress of time is slowed down and consequently all processes taking place in time.

We see that in a rocket traveling at a rate close to the speed of light, the progress of time must be slowed down according to the laws of relativity theory. Any physical device (a spring or quartz clock, or a radioactive time standard) and even the human heart indicate to us that during the period of flight to Proxima Centauri and back, 4 years less time has passed inside the rocket than on the earth. Or, if the inertial portion of the rocket flight is considered, time for travelers moving at 250,000 km/sec will progress 1.8 times slower than for someone on the earth.

Why is it that we do not experience a slowing down of time in actuality? Why is it that pilots arriving at an airport do not notice that their time is passing slower than on the earth? Because, at small velocities (compared with the speed of light) the time difference will be unnoticeably small.

Artificial satellites travel around the earth with great speed. Of course, their rate of motion (8 km/sec) is very small compared to the speed of light and the slowing down of time is very insignificant. It can, however, be measured.

The Soviet scientist V. L. Ginzburg proposed equipping one of the artificial earth satellites with an accurate clock and comparing its indications with those on the earth in say a year after launching the satellite. A lag of $^1/_{100}$ of a second accumulated during this period would be a new and outstanding triumph of the special theory of relativity.

Even on a rocket completing a year's flight through the solar system with an average velocity of 15 km/sec, the clocks will differ from those on the ground by only 0.015 sec. At a velocity of 1,500 km/sec the annual difference amounts to fully $2^1/_2$ min, at a velocity of 150,000 km/sec the difference is 18 days, at a velocity of 255,000 km/sec the time gain is doubled (6 months), and if the velocity were to differ from the speed of light by 100 km/sec the time gain would be increased by 35 orders of magnitude! At such a velocity one year will pass on the rocket while 38 years pass on earth and passengers returning from their seemingly brief journey will find that back on earth their children are elderly people and their grandchildren are adults while they themselves have aged only one year. The closer the rate of motion is to the speed of light, the more difficult to attain, since the usual rules for velocity addition become inaccurate and cannot be used.

Suppose a rocket is traveling at a velocity $v_1$ and a second rocket is launched from it in the same direction with a relative velocity $v_2$. The velocity of the second rocket with respect to the earth will then be

$$v = \frac{v_1 + v_2}{1 + \frac{v_1 v_2}{c^2}}.$$

If, for example, $v_1 = v_2 = \frac{c}{2}$ the final velocity will not be $\underline{c}$ but only $^4/_5$ c.

Occasionally one hears of biologists expressing the idea that slowing down of time can have no effect on aging of the living organism since the human organism is adapted to a definite, "terrestrial" life rhythm. They also say that the laws which apply to elementary particles cannot be extended to highly organized material forms.

These and other statements are not true. First of all, we are not talking about the slowing down of any processes within the moving rocket but only of a slowing down in the passage of time in a physical sense. In order to maintain its biological life rhythm, the living organism must simply live in accordance with the time which passes in the rocket. Incidently, the cosmonaut himself has no way of detecting any variations in the passage of time. From his point of view everything will proceed the same as it did on earth.

The second objection is also erroneous. General laws of nature apply equally to both animate and inanimate bodies (the law of universal gravitation, the laws of motion, etc.). We have seen that "elementary" particles do indeed conform to the laws of relativity theory. Since all bodies in the universe, including living organisms, consist of elementary particles in which processes are relatively slowed down during motion at high velocities, the same laws will certainly apply to all of these bodies. Therefore, the assertion that interstellar

travelers will be relatively younger after an extended voyage and return to the earth than terrestrial, "stationary" inhabitants is in fact true.

## Time Paradox

The phenomenon of time retardation in a rocket traveling near the speed of light seems, all by itself, to be paradoxical. But this phenomenon may not acceptably be called a "time paradox" or "clock paradox." A major paradox still lies before us.

We have already stated that all motions are relative. The rocket moves with respect to the earth but, on the other hand, within the system of the rocket the earth also moves at nearly the speed of light with respect to the rocket. This means that from the viewpoint of the rocket passengers time must be slowed down on the earth! It seems that we have encountered a contradiction.

Actually there is no contradiction. The secret is that according to the laws of relativity theory the earth system and the rocket system are equitable only if they move uniformly and rectilinearly with respect to each other. As long as this is the case a clock on the rocket will be retarded in the earth system while, conversely, a clock on the earth will be slow within the system of the rocket. As long as the earth and rocket are located at different points in space it is not possible to compare these clocks.

So as to compare time elapsing on a moving body with that on a stationary body it is necessary to proceed as follows. Imagine ourselves in an interstellar rocket. The rocket passes close to the earth and at that moment we compare our clock with one on the ground. They indicate the same time. We must then travel past another stationary object on which there is a clock synchronized with the one on the

earth and we again make a time comparison. Here we see that according to our clock less time has elapsed than is indicated by the clock on the stationary object. If we consider ourselves to be stationary with the earth being carried past us it is then necessary to compare the terrestrial clock with the two clocks located within the stationary frame of reference. In this case the terrestrial clock will be slower than ours.

From this we see that the process of time variation is nonsymmetrical with respect to moving and stationary frames of reference. In the moving system it is sufficient to have one clock, but in a stationary system it is necessary to have a minimum of two clocks in order to make a time comparison. Any clock moving with some velocity with respect to the stationary frame of reference will always be slow.

If there are two clocks one of which describes a closed trajectory and returns to the original location (for example, the traveler who has flown a closed curve around the earth in a photon rocket) the reference systems are not equal. In order to compare clocks the rocket must return, alter its speed, and direction, and return to the earth. This means that during part of its flight the rocket will move with an acceleration. But the laws of special relativity theory, which are valid only for inertial systems, cannot be applied to a system undergoing acceleration. In this case we must apply the laws of general relativity theory.

We will not deal with this question in detail. We will limit our interest to the single conclusion, from relativity theory, that the passage of time depends not only on the motion of a body, but also on the presence of magnetic fields. In a strong magnetic field the passage of time is retarded. As a result of this, there is an observed variation in the frequency of oscillation of atoms on the sun compared

to those on the earth (since the gravitational field at the surface of the sun is much stronger than on the earth). This effect is even greater on certain stars, white dwarfs, which may be a hundred thousand times more dense than a planet. The gravitational field at the surface of such a star is tremendous and time retardation is evident by a displacement of the star's spectral lines toward the red (this indicates that the frequency of oscillation of atoms is reduced, i.e., time is retarded). This effect has complicated astronomical observations.

General relativity theory also establishes the principle of a relationship between accelerations of a moving system and gravitational fields. It indicates that any acceleration of the system has the same effect on it as the application of a certain gravitational field.

The basic quantity determining the progress of time in a given system located in a gravitational field or in a state of accelerated motion (which, as we have already seen, is arbitrary) is the gravitational potential. Gravitational potential is numerically equal to the work which must be expended against the force of gravity in order to move a unit mass to infinity. It is not difficult to realize that this work is equal to the product of gravitational acceleration and the distance from the center of the body providing the gravitational field. In the case of an accelerated motion of a rocket, the acceleration potential will be analogously equal to the product of the rocket's acceleration and the distance from it (in the direction opposite to that of the acceleration). The latter requirement results from the fact that under accelerated motion we experienced a force which forces us backwards against the motion. The direction of the potential coincides with the direction of the force.

Let us now apply all of this information to the motion of our interstellar rocket. While the rocket is gathering speed close to the earth (with a constant acceleration) the difference in potentials of the earth and the rocket is not great since the distance between them is small. To passengers on the rocket it seems that the terrestrial clock is slowing down, though not yet significantly. Now the rocket is approaching a star and begins to slow down. The acceleration is now directed back toward the earth and the acceleration potential is greater on the rocket than on earth. The difference in potentials (earth minus rocket) which determine the slowing down of earth time will in this case be negative, i.e., the clock on the earth begins to run fast! And since the distance between the earth and the rocket is great the terrestrial clock will gain time very rapidly.

Let us make a few calculations. The relative variation in time rate will in this case be

$$\frac{\Delta t}{t} = \frac{aR}{c^2}.$$

where a is the acceleration, R is the distance between the rocket and the earth and c is the speed of light. If $a = 10$ m/sec$^2$ $= 1000$ cm/sec$^2$ (acceleration due to earth's gravity), the distance to Proxima Centauri $R = 4 \cdot 10^{18}$ cm, and $c = 3 \cdot 10^{10}$ cm/sec, then

$$\frac{\Delta t}{t} = \frac{10^3 \cdot 4 \cdot 10^{18}}{9 \cdot 10^{20}} = 4.4.$$

In other words, within the system of the rocket, time on earth as the rocket slows down and as it accelerates to return to the earth, will pass 4.4 times faster than time on the rocket. The terrestrial clock rapidly overtakes the rocket's clock and goes on ahead. And although during the last (inertial, toward the earth) stage of flight the terrestrial clock is slowed down somewhat, the total result will be

as if, from the point of view of an earth inhabitant, the earth clock was ahead of the rocket's, i.e., that time passes more slowly on the rocket than on earth.

By way of illustration a table is provided which shows the "time balance" during a rocket flight to Proxima Centauri according to the scheme acceleration — inertial flight — deceleration assuming an inertial flight velocity of 250,000 km/sec. The time which has elapsed on the earth and on the rocket during each portion of the flight is given from the point of view of each system (earth and rocket).* The same situation is illustrated in Figs. 2 and 3 where the broken line indicates the progress of a clock on the earth while the solid line indicates the rocket's clock.

Time on Earth and in Rocket During Flight to Proxima Centauri and Back, Years

| Flight Stage | Earth system | | Rocket system | |
|---|---|---|---|---|
| | Earth | Rocket | Earth | Rocket |
| Acceleration while leaving earth . . . . . | 1,45 | 1,14 | 0,80 | 1,14 |
| Inertial flight . . . . | 3,33 | 1,85 | 1,03 | 1,85 |
| Deceleration at the star | 1,45 | 1,14 | 4,40 | 1,14 |
| Period of stay in stellar system. . . . . | 1,00 | 1,00 | 1,00 | 1,00 |
| Accel. while leaving star | 1,45 | 1,14 | 4,40 | 1,14 |
| Inertial flight . . . . | 3,33 | 1,85 | 1,03 | 1,85 |
| Deceleration at earth . | 1,45 | 1,14 | 0,80 | 1,14 |
| Total . . . . . | 13,46 | 9,26 | 13,46 | 9,26 |

The interstellar traveler has experienced acceleration while the earth has not and therefore the traveler's clock slows down and not the terrestrial clock. Thus the time "paradox" is explained.

At one time the concepts up and down were considered absolute. People did not believe that the earth was a sphere and in their opinion inhabitants of the other side of the earth would have to walk with

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* Calculations by I. D. Novikov, graduate student at Moscow University.

their heads downward. People were then convinced of the spherical shape of the earth but considered it absolutely stationary. These attitudes seem naive to us now. However most of our contemporaries consider time to be some kind of an absolute period. We became used to the relativity of such physical phenomena as velocity, acceleration, and motion. In precisely the same way our descendants will be accustomed to the relativity of the concepts of time, distance, and mass. Perhaps some of our views will seem as naive to them as the concepts of a stationary earth or a flat earth seem to us. The further human intellect penetrates the limitless vastness of the universe and the most guarded secrets of nature, the more clearly and completely will the laws of the material world be disclosed to us.

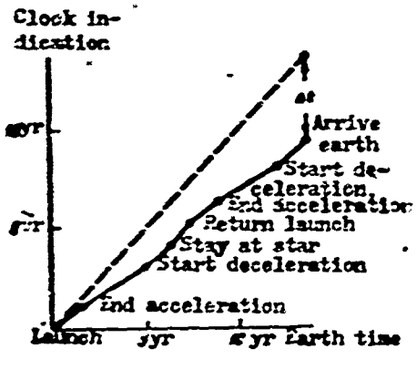


Fig. 2. Time graph in earth system.

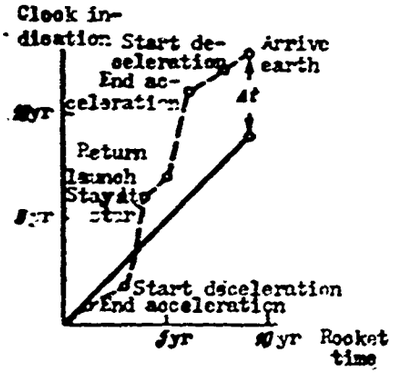


Fig. 3. Time graph in rocket system.

## Is Interstellar Flight Safe?

Let us proceed to a description of other interesting effects which may be anticipated by future interstellar travelers aboard a photon rocket.

We will first be concerned with the question of flight safety.

Despite the fact that cosmic space is very tenuous and the density of the interstellar substance is scarcely greater than $10^{-24}$ g/cm$^3$ at

high flight velocities individual microparticles and atoms of various elements, particularly hydrogen, i.e., protons, will collide with the skin of the rocket. The occurrence of protons in a substance with a density of $10^{-24}$ g/cm$^3$ is about one per cubic centimeter. Traveling at near the speed of light (i.e., about 300,000 km/sec) each square centimeter of the ship's skin experiences collisions with about $3 \cdot 10^{10}$ particles (protons) per sec. Since the mass of a proton is $1.7 \cdot 10^{-24}$ g/cm$^3$, each square centimeter of the ship's skin receives a mass of $5 \cdot 10^{-14}$ grams. This mass will carry an energy $c^2$ times greater, i.e., on the order of $5 \cdot 10^7$ ergs.

We notice that the energy of 1 gram of TNT amounts to $10^{10}$ ergs. Thus, it will be as if 0.001 grams of TNT were detonated on each square centimeter of the ship's surface every second. However, it is not possible to draw a complete analogy between the detonation of TNT and collisions with elementary particles. The detonation of TNT would be completely expended on deformation and disintegration of the skin. The encounter of elementary particles by the ship's skin at such velocities would, however, result in various nuclear processes which lead, in particular, to the appearance of $\gamma$-radiation and X-rays. In this case the substance of the skin would be destroyed more gradually than by the detonation of TNT, the bulk of the energy being converted to radiation which it is easy to shield against.

It seems to us, however, that the problem of shielding need not disturb us yet. We remember that when the first train made its appearance certain skeptics considered traveling on a train at a rate of 30-50 km/hr was not possible for people because of the landscape rapidly flashing past the window. Of course, it is natural to be concerned about the safety of interstellar flights but it is not necessary to skeptical. If people succeed in mastering the photon engine it

would be sufficient to direct a small portion of its energy forward in the form of a powerful electromagnetic beam to deflect all of the charged particles in front of the space ship and simultaneously ionize the uncharged particles so as to force their deflection also in the magnetic field of the ship. This beam will make the space in front of the space traveler almost absolutely pure, protecting the ship from encounters with small cosmic bodies.

The view of the sky which will confront the eyes of future space travelers moving at near the speed of light will be unusual. As the result of Doppler effect, stars located in the forward direction would, as the speed increased, become more and more blue, turn violet, and then their radiation would become invisible. They would be ultraviolet. Stars behind the spaceship, on the other hand, would become more reddened and their radiation would become infrared.

In addition to this effect there would be a so-called stellar aberration. Even on the earth, which travels at a speed of 30 km/sec, stars appear to be displaced in the direction of the earth's moment by an angle of 20" because of the fact that although the speed of light is high, it is not infinite. We observe a similar effect when watching snow from the window of a train. The snowflake paths are always inclined in the direction of the train's movement. In a rocket traveling at near the speed of light the angle of the aberration would be quite large (tens of degrees) and all stars appear to be displaced in a forward direction with respect to the motion of the rocket.

Because of the combination of both these effects, stars will be seen exclusively in a small ring somewhat in the forward direction with respect to the ship's course. As the speed of the ship increases to approach that of light, this ring will continually converge and move further forward. The appearance of constellations will also be distorted.

## To the Andromeda Nebula

Despite all the interest in interstellar travel it may be shown that man cannot travel further than the closest neighbors to our sun. For example, a single human lifetime does not suffice for a trip to Betelgeuse and back even at a speed of 250,000 km/sec. Flying anywhere without the assurance of returning is absurd and such a flight would be of no use to humanity.

Does this mean that our descendants will not be able to realize the dream of the heroes in I. Yefremov's novel Andromeda Nebula and reach another galaxy? The German physicist E. Zenger thinks that it is possible. The Andromeda Nebula, which lies 1.5 billion light years from us, may, it appears be reached in 27 natural years.

In order to understand how this can be, let us give some consideration to the mechanics of photon rocket flight. Let us assume that the crew tabulates the proper time of the rocket with an ordinary chronometer and with some kind of spring-loaded device measures the proper acceleration of the rocket. Knowing these two quantities it is possible, using the ordinary formulas of mechanics, to calculate the proper velocity and the proper course taken by the rocket. For simplicity let us assume that the rocket is moving with a constant proper acceleration which for the sake of the crew may be made equal the force of terrestrial gravity (9.8 $m/sec^2$). During half of the journey the acceleration would be directed forward and during the second half toward the rear, i.e., the rocket would be slowed down. In contrast to the example given above, there will be no inertial portion to this light.

Observing from the earth the rocket's flight, it is possible to independently determine its proper velocity, acceleration, course, as well as time in the terrestrial reference.

What are the relationships between these and similar proper quantities measured within the rocket's reference system? We have already considered the connection between terrestrial time and the proper time of the rocket. We have seen that as the relative velocity of the rocket approaches the speed of light the ratio of these times must increase rapidly. In order to make all of this clearer we shall take as a basis the ratio of the velocity of the rocket to the speed of light and call it the Einstein number. Obviously, the relative Einstein number will never exceed unity but the proper Einstein number may exceed unity as much as desired. In other words, proper velocity may be much greater than the speed of light.

Doesn't this contradict the basic proposition of relativity theory? No, because proper velocity, like proper course heading, is not characterized by the relative velocity and distance of the rocket from the earth. This quantity is only conditionally called "velocity." But proper velocity (more accurately, proper Einstein number) determines the propellant discharge rate of the rocket. That is, this number must be introduced into the famous rocket formula developed by Tsiolkovsky in order to determine the relationship between its initial and terminal mass (Tsiolkovsky number).

We remember that in calculations for a typical rocket the Tsiolkovsky number is one of the basic quantities on which the velocity developed by the rocket at the moment its engines terminate operation depends. Knowing the exhaust velocity of gases through the nozzle and the required velocity of the rocket itself, the designer determines the Tsiolkovsky number and multiplying it by the mass of the payload he obtains the initial mass of the rocket and therefore the required amount of fuel.

As we know, the quantity of mass ejected from the rocket and its velocity u are united by the classic Tsiolkovsky formula:

$$\frac{M}{M_0} = 1 - e^{-\frac{u}{v}},$$

where v is the discharge velocity from the rocket nozzle, $M_0$ is the initial mass of the rocket, M is the mass ejected from the rocket at any given moment of time, and e is the natural logarithm base. This formula is inapplicable however for cases of motion at high velocity or when the flow of discharged matter through the rocket nozzle reaches velocities close to the speed of light. Here one must use the generalized Tsiolkovsky formula which has been derived by a number of scientists and has the form:

$$\frac{M}{M_0} = 1 - \frac{\left(1 - \frac{u}{c}\right)^{\frac{c}{2v}}}{\left(1 + \frac{u}{c}\right)^{\frac{c}{2v}}}.$$

It is clear from this relationship in particular that the velocity of light represents the highest attainable velocity. It is achieved when $M = M_0$, i.e., when the entire mass is discharged.

In the case of a photon rocket $v = c$ and the relationship acquires the simple form:

$$\frac{M}{M_0} = 1 - \sqrt{\frac{1 - \frac{u}{c}}{1 + \frac{u}{c}}}.$$

For example, when 90% of the rocket's mass is combusted, i.e., when $\frac{M}{M_0} = 0.9$, we have: $\frac{u}{c} = 0.98$.

Analysis of these formulas indicates that only when the exhaust velocity $v \approx c$ is it possible to attain high velocities for reasonably

allowable values of $\frac{M}{M_0}$. Even when v = 15,000 km/sec, in order to attain a velocity of 100,000 km/sec, it would be necessary to "burn" so much substance that it would prove very difficult technically:

$$\frac{M}{M_0} = 1 - \left(\frac{1}{2}\right)^{10} = 1 - 0{,}001 = 0{,}999.$$

This means that it is necessary to burn 0.999 of the mass and then 0.001 of the mass attains the indicated velocity.

After the photon rocket has gotten up speed the change in time during inertial flight in the rocket and the corresponding change in time on the earth will be associated with the discharge of mass from the rocket by the following simple relationship

$$t' - t'_0 = 2(t - t_0)\frac{M_0 M'}{M_0^2 + M'^2}, \quad M' = M_0 - M,$$

where $t_0$ and $t'_0$ are time elapsing within the earth and rocket systems until the moment the discharge of propellant through the nozzle is discontinued.

In the photon rocket the role of propellant is played by a supply of particles and antiparticles which are subject to annihilation. The quantity of this supply needed for the flight is determined by the maximum proper Einstein number attained at midflight.

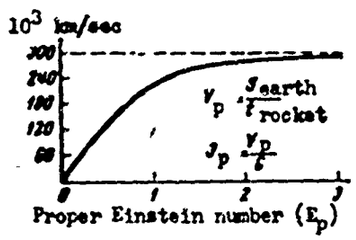


Fig. 4. Velocity as a function of Einstein number.

Figure 4 shows the relationship between relative and proper Einstein numbers (in other words, between relative and proper velocities). Proper velocity increases proportionally with proper time while the relative velocity of the rocket increases more and more slowly, gradually approaching the speed of light. Figures 5 and 6 show the change in the relationship between relative

and proper time and acceleration. From Fig. 6 it is clear that although proper acceleration is always the same, relative acceleration rapidly decreases, approaching zero.

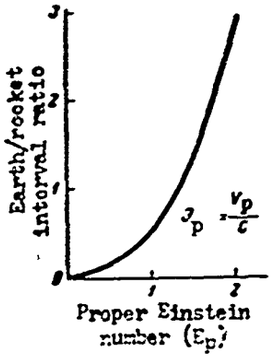


Fig. 5. Time as a function of Einstein number.

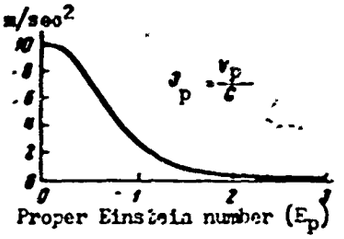


Fig. 6. Acceleration as a function of Einstein number.

It is interesting to note that the relative course heading determined from measurements made on the rocket equals neither the course heading measured from the earth nor the proper course heading in the rocket system. This ties in with the shortening of distance in the direction of rocket motion which we are already well acquainted with.

Let us now try to measure from the earth, with conventional astronomical methods, the interval of space covered by the rocket and we will divide it by the elapsed interval of proper time on the rocket. We obtained yet another velocity, proper-time velocity. This apparent velocity, which has no physical significance (since distance and time were measured in different reference systems), provides at the same time an indication of the effectiveness of our rocket from the point of view of its crew. It indicates at what moment proper time the rocket will intersect some astronomically known distance.

Let us return to the flight conditions. If the rocket accelerates half the way and decelerates the other half the greatest velocity will be attained, of course, at midflight. The proper time of the flight

will then depend only on distance (Fig. 7). This indicates that a flight to Proxima Centauri with such a schedule takes 3.6 proper years or 6 terrestrial years, a flight to the center of our galaxy requiring 19.8 proper years corresponding to 30,000 terrestrial years, a flight to the Andromeda Nebula 27.2 proper years or 1.5 million terrestrial years and, finally, a flight to the most distant galaxies visible through the largest available telescopes would take 41.9 proper years or 3 billion earth years. The same would be required for the return flight.

Of course, it cannot be denied that Yefremov's hero could reach the Andromeda Nebula in 27 proper or "dependent" years, but a new obstacle arises here, namely, the Tsiolkovsky number (i.e., the ratio of initial mass to terminal mass) turns out to be 2.5 trillion ($2.5 \cdot \cdot 10^{12}$)! From 2.5 million tons of initial mass, 1 gram will reach the Andromeda Nebula. If provision is made for returning, this figure of 2.5 trillion must be squared. Meanwhile, 3 million years will have passed on the earth.

Is there any sense in starting out on such a flight? The future will answer this question. At present, flying to the Andromeda Nebula can be only a theoretical matter.

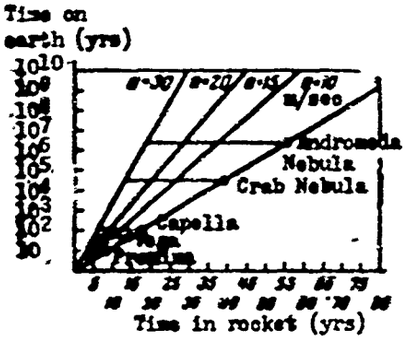


Fig. 7. Travel time to various stars and galaxies (in earth and rocket reference systems) for various accelerations a.

## When?

Let us return now from our imaginary journeys to the real, present-day earth and attempt to answer the difficult question of when man will be able to fly into the stars.

It is not easy to answer this question. Indeed, the difficulties to be overcome are great. The photon rocket is still only an engine in principle, not because of construction difficulties but because of those theoretical obstacles which we have cited above. Until now we have been speaking about photon rockets. This, however, is a dangerous rocket. Clearly, with the development of quantum generators and quantum accumulators of light energy, it is possible to talk about the use of these "machines" for producing a reactive thrust. Converting nuclear energy for charging these generators photons of a definite frequency, it would then be possible to directly charge the generators with a wavelength which could almost completely be reflected from a mirror without significant heating or deformation of it.

Of course, it can scarcely be expected that people will fly to other stars within the present century, work within our own solar system will suffice. But we believe that the people of the future communist community will successfully solve this problem and perhaps faster than we yet suppose.

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# CREATION OF HABITABLE MEDIUM IN FUTURE SPACE FLIGHTS OF MAN

A. A. Nichiporovich

Starting of first Soviet earth satellite accomplished five years ago, was turning point in mastering by man of cosmic space. It was signalized transition from scientific fabulousness, from theoretical development of possibilities of flight of man in cosmic space to practical solution of this problem, for a long time occupying human imagination.

For five subsequent years events of no lesser significance occurred, starting of rockets on given trajectories in circling of moon, in direction of Mars and chiefly flights of satellites around earth with living creatures, and then with first hero — astronauts Yu. A. Gagarin, G. S. Titov, A. G. Nikolaev and P. R. Popovich.

Each of these events is the greatest achievement of human genius, and the most important historical event; however this is only threshold to flight of man beyond the limits of earth, to regular mastering of cosmic space on a large scale. Undoubtedly, it is near that time when man, detaching himself from Earth, will accomplish flight to Moon, then to the nearest planets of solar system, and in future even beyond its limits.

If we appraise such flights from the point of view of technical possibilities, then accomplished starting of our cosmic apparatuses indicate that technical side,

considering starting in any given direction, is close to proper solution. But this is only part, although a very important one, of all that is necessary for space flight of man; man must not only be guided into outer space, ensuring flight on necessary trajectory and return to Earth, but also it is necessary to create for him during flight and during stay at intermediate stations, on Moon or on planets, a normal ecological medium: normal feeding, proper composition and pressure of surrounding atmosphere, and proper temperature and humidity conditions.

We will describe stay of man, for instance, on the moon, Mars or Venus. On all these cosmic bodies temperature conditions, atmospheric pressure (up to absence of any atmosphere, for instance, on moon), composition of atmosphere, gravity are sharply different from the terrestrial.

On moon man will not find water and food. It is possible that such a situation will be encountered also on the nearest planets. During brief stay, for instance on moon, man can inspect its surface, moving in special pressure suits, but with this he should have base which would ensure him food, water, and oxygen for breathing, where acceptable atmospheric pressure would be maintained.

Such a base for brief stops can be spaceship itself, but for prolonged stay for the purpose of thorough mastering of our natural satellite--special hermetically sealed locations, such in volume and construction that man could live and work there under conditions and in a setting close to conditions of his life and activity on Earth. In Fig. 1 is depicted prospective base of man on Moon; it is presented by Japanese scientists.

In one or another degree man must encounter similar conditions also on other celestial bodies, since not on one even of planets closest to us will we find conditions identical to conditions of Earth. And meanwhile biological capacity for adaptation of man to complex of conditions in the terms in which it exists on surface of Earth is very strictly specific, and range of adaptable possibilities we have is comparatively small.

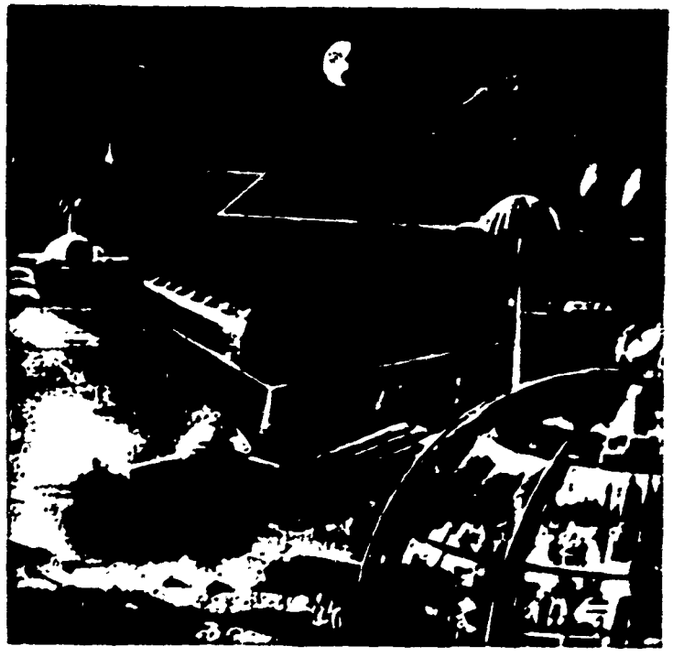


Fig. 1. Proposed form of base of man on Moon (from work of Japanese scientists).

For instance, let us remember if only how heavy man is already at height of 10,000 meters from surface of Earth or under water during conducting of caisson works. And range of possible variation of conditions which must be encountered by man in cosmic space is incomparably larger.

Hence, it is almost inevitable that in cosmic space man all the time must be in limited closed systems—be that spaceship itself, intermediate interplanetary artificial station or hermetically sealed living and working quarters on cosmic bodies.

One of important conditions of normal ecological medium is uninterrupted supply of man with necessary food.

We will present best variant, when man can appear on planet where there is life and living organisms. But it is doubtful whether even in this case he will be ensured normal feeding. In fact, we remember that from huge variety of organisms on Earth only insignificant part of them can give man full value food.

In difficult years of Great Patriotic War there were issued directions and recommendations for search and use of plants of local flora useful for feeding. Lists contained only insignificant part of forms of given flora, but even these plants could ensure man only the scantiest and most inferior feeding.

Man can appear in such a position even on Earth, surrounded by nature with which he has been in interaction tens of thousands of years. Is it possible in such a case to guarantee that man as successfully will be able to use living matter on other celestial bodies—in nature, way of appearance and development of which were other than on Earth and never came in contact with ways of development of man?

Thus, probably, in all cases man will not find in cosmic space conditions which could satisfy him, and in flights it will be necessary to create for him medium necessary for himself in closed isolated and hermetically sealed constructions, but all the more so in spaceship, by special methods.

In addition to all this the problem of creation and maintenance in isolated constructions of needed medium could be in a number of cases not especially complicated, if man was not himself in extraordinarily intense interaction with medium and himself did not change it extraordinarily fast and strongly.

## Directions and Results of Interaction of Man With Environment

Approximate results of interaction and exchange of man with external medium during one day in average rounded figures are depicted in Fig. 2.

In process of vital activity man expends energy and draws it from organic substances, gradually oxidizing them with the help of oxygen and forming as a result of this carbon dioxide and water. Schematically this process can be represented by the following chemical equation

$$C_{10}H_{20}O_6 + 12\,O_2 \rightarrow 10\,CO_2 + 10\,H_2O + 1375 \text{ kilocalorie}$$

whereby total formula $C_{10}H_{20}O_6$ are depicted organic substances whose oxidation leads to formation of approximately 0.83 l of exhaled carbon dioxide in exchange

for every liter of oxygen* inhaled and consumed in processes of oxidation.

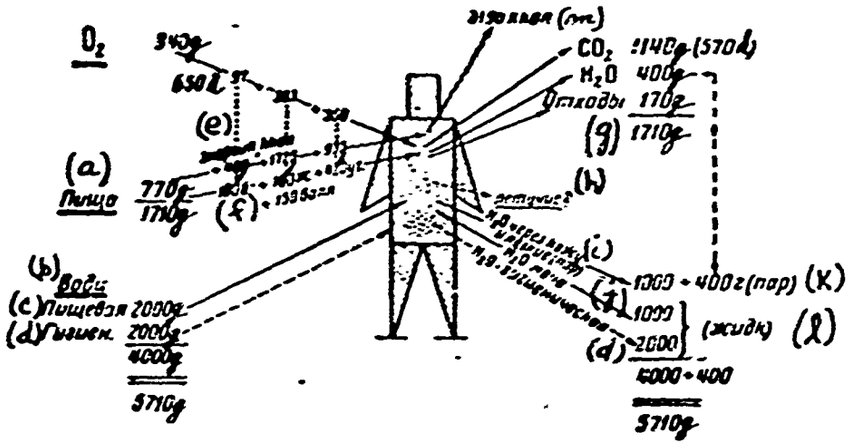



Fig. 2. Results of twenty-four hour interaction of man with medium. On the left are necessary quantitites of full value consumable substances and products: On the right--quantities of final products of vital activity requiring purification (water), removals from system or chemical transformation into full value products.
KEY: (a) Food; (b) Water; (c) Nutritive; (d) Hygienic; (e) Energy; (f) 100 of proteins + 100 of fats + 420 of carbohydrates + 150 of inert material kilocalorie; (g) Waste; (h) Volatile; (i) Through skin and lungs (vapor); (j) Urine; (k) Vapor; (l) Liquid; (m) kcal.

For normal maintenance of vital activity man on the average should extract in 24 hours from respiratory material of organic substances near 3000 kilocalories of energy. With the help of this energy reactions of syntheses and transformations of subtances are carried out, man accomplishes various work, maintains at necessary level (near 37°C) temperature of his own body and finally liberates "worked" energy in the form of heat into environment. These expenditures have to be compensated by mastering of organic substances and number of salts from food. For compensation is necessary food containing near 100 g of protein, 100 g of fat and 420 g of carbohydrate, i.e., near 620 g of assimilated substances. If food is of good quality and full value, then by weight the share of assimilated substances can amount to near 80% in it. Remaining food--20% (in this case near 150 g) will be excreted subsequently in the form of excrements.

*In this case respiratory coefficient (relation of volume $O_2$, to $CO_2$) is equal to 1.2. Such respiratory coefficient has place for feeding man with high-quality caloric food. In other conditions it can be less and even approaches unity.

Thus, man should obtain in twenty-four hours near 770 g of full value food. Adult man (whose body weight is stabilized) oxidizes and gives off into environment a corresponding quantity of substances by weight.

If we consider that man receives in day 770 g, then usually 620 g of them are subjected to oxidation, on which is used near 940 g (650 l) of oxygen. There also will be formed and given off into environment 1140 g (570 l) of carbon dioxide, 400 g of water and near 3000 kilocalories of energy in the form of heat, depreciated and irrecoverable for further vital activity. Furthermore, man eliminates in the form of excrements near 150 g of unassimilated food substances and near 20 g of final products of metabolism in composition of urine and in the form of a number of volatile substances (ammonia, hydrogen sulfide, volatile organic substances) through skin and lungs.

As a final result, man in the course of twenty-four hours transforms 1710 g of oxygen and food and 3000 kilocalories of chemical energy into carbon dioxide, water, and also into solid, liquid and volatile wastes of vital activity.

Still in larger quantities man will depreciate in closed systems water of which he must consume minimum of 4 kg; 2 kg in food and for drinking and 2 kg for hygienic purpose. Approximately 1 kg of this water man gives off through skin and lungs in the form of vapor into atmosphere, and 1 kg in the form of urine and 2 l in the form of worked and contaminated hygienic water.

Thus, man consumes in 24 hours near 5.5-6.0 kg of full value substances and 3000 kilocalories of chemically combined full value energy and transforms them into inferior, contaminated and even harmful substances, and 3000 kilocalories of energy is irreversibly dispersed in the form of heat into environment.

For maintaining normal ecological medium in closed space, expended full value substances and energy must be recreated anew or be compensated from reserves, and finally, unnecessary and harmful substances must be liquidated.

## General Principles of Creation of Normal Ecological Medium in Closed Spaces

Various principles and methods can lie in framework of creation and maintenance in space flights of normal ecological medium.

It would have been possible to talk about removal of harmful and depleted substances overboard the ship or of closed system and accomplishment of feeding, supply of oxygen and water at the expense of reserves taken from Earth or specially created at intermediate stations. However, application of this principle in pure form in prolonged flights is unrealizable for many reasons.

Thus, reserves taken from Earth must be very large, 5-6 kg per day per man, but removal overboard of gases and liquids into cosmic space is impermissible, in order not to put into cosmos embryos of terrestrial life and organic substances, hampering thereby possibility of discovering there extraterrestrial forms of life. For this reason system based exclusively on maintenance of vital activity of man at the expense of reserves from Earth can be acceptable only in the simplest cases and for relatively brief flights.

In more complicated cases and for prolonged flights method of regeneration or restoration of initial full value substances from final inferior and waste products must be used. In principle this problem can be solved most simply with respect to water: it is not subjected to chemical change and decomposition and remains the same water, but only either contaminated or converted into vapor state. Consequently, regeneration of water should consist first of condensation of its vapors, and secondly of purification of it with bringing up to conditions fixed for nutritive and hygienic water. For this and for the othere there exist not a few fundamental possibilities and this part of the problem can be solved completely successfully.

But here there is one essential difficulty, the fact that as a result of vital activity of man and oxidation by him of organic substances the quantity of

water in system all the time will be increased (approximately 400 g in day per man). What to do with this water? In order not to supersaturate with water the atmosphere of ship, it is necessary either to eject it overboard (which is difficult), or to condense and save it in special closed vessel, all the time supplementing it (what is hardly rational), or, finally, to subject it to chemical processing, obtaining from water some other useful substance. Such a substance can be, for instance, oxygen. And indeed, water can be subjected to electrolysis, decomposing it into oxygen and hydrogen,

$$2H_2O \xrightarrow{\text{electrolysis}} O_2 + 2H_2$$

In principle this is a rational method and in flights of short duration of it can be used as means of obtaining oxygen from special reserves of water.

But in systems based on full rotation of substances, it would have been possible to subject to electrolysis only newly formed and increased in quantity water of metabolic extraction, i.e., separated in the course of oxidation of organic substances, but it is not formed so much--only about 400 g in twenty-four hours per man, and even if all of it is subjected to electrolysis, then it will be possible to obtain only 360 g of oxygen, whereas man consumes 940 g of it.

However, even such electrolysis of water could bring some benefit: First, by this means in ship newly formed unnecessary water would be liquidated and secondly, in some degree problem of supply of man with oxygen would be facilitated. But this would be only partial solution of problem and, furthermore, in system would be stored free hydrogen, which is not safe from the point of view of possibility of explosion. As component of ecological medium free hydrogen is not needed in system.

Analyzing the example with regeneration of water, we touched two different in principle methods of possible regeneration of full value substances: First, are methods of physical regeneration--condensation of steam, purification of contaminated water, and, secondly, methods of chemical regeneration, where it is possible to

strive to recreate from final products of exchange one or another of initial full value substances. Regarding second problem, then complete resolution of it purely by chemical means is difficult and probably a practically unrealizable matter. Let us illustrate this by the following example.

We said above that owing to electrolysis of water it is possible to obtain part of needed oxygen. But where can remaining part of it be obtained and what can be done with Hydrogen? Reasoning theoretically, oxygen could be obtained from carbon dioxide ($CO_2$), for instance, owing to its decomposition into CO (carbon monoxide) and $O_2$

$$CO_2 \longrightarrow CO + 1/2\ O_2$$

or even into free carbon and oxygen.

$$CO_2 \longrightarrow C + O_2$$

These processes are possible in principle, but are very energy-consuming and practically are realizable with difficulty. But even if it was possible to accomplish them along with electrolysis of water in real flight conditions, then this still would not be complete solution of question: with this would be obtained necessary oxygen for normal ecological medium, but unnecessary carbon, carbon monoxide and hydrogen would be stored. In principle there exists some possibility of using these substances, forcing them with help of catalysts (and expending on this additional energy) to react among themselves, for instance hydrogen with monoxide or even with carbon dioxide, and of obtaining some organic substances: methane, from aldehyde or some others of comparatively simple structure,

$$CO + 3H_2 \longrightarrow \underset{\text{methane}}{CH_4} + H_2O$$

$$CO_2 + 2H_2 \longrightarrow \underset{\text{formaldehyde}}{CH_2O} + H_2O$$

However, from the point of view of maintaining normal ecological medium such reactions would be almost useless: hydrogen obtained from metabolic water would suffice only for treatment of part of formed $CO_2$, and besides this would be obtained additional unutilized products--methane and formaldehyde.

It would have been possible to use methane as source of energy, for instance to burn it for preparation of food. But this would be an absolutely senseless operation, since burning of methane would lead to intensive consumption of free oxygen and repeated formation of but again unnecessary products, carbon dioxide and water, and, furthermore, liberated energy would be only part of that energy which had to be preliminarily expended on synthesis of methane from water and carbon dioxide.

Synthesis of methane

$$\begin{cases} CO_2 - \text{energy} \rightarrow CO + 1/2\ O_2 & (1) \\ 3H_2O - \text{energy} \rightarrow 3H_2 + 1\ 1/2\ O_2 & (2) \\ CO + 3H_2 + \text{energy} \rightarrow CH_4 + H_2O & (3) \end{cases}$$

Burning of methane $CH_4 + 2O_2 \quad CO_2 + 2H_2O + \text{energy}$

As can be seen, consecutive realization of these reactions would lead us into initial state in the sense of balance of chemical products: that free oxygen which would be obtained owing to electrolysis of water and decomposition of $CO_2$ would be wholly consumed in burning of methane.

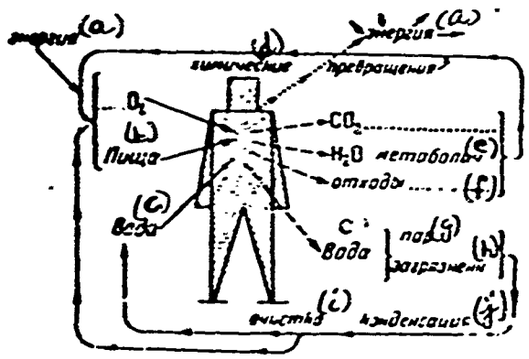



Fig. 3. Diagram of ideal case of regeneration of composition of air, food and water in closed system.

Drinking and hygienic water is condensed and purified. Substances separated during purification of water, $CO_2$, and metabolic water are subjected to chemical changes with formation of full value food and free oxygen.
KEY: (a) Energy; (b) Food; (c) Water; (d) Chemical conversions; (e) Metabolic; (f) Waste; (g) Vapor; (h) Contaminated; (i) Purification; (j) Condensation.

Thus, of the above-indicated reactions the only practically useful one could be reaction of electrolysis of metabolic water with obtaining of free oxygen. However, it gives only partial solution of question*. Its complete solution could take place when such a system of processing the final products of vital activity of man was used, with which they would be completely transformed into the initial full value products: contaminated and vaporized water into full value drinking and hygienic water, and $CO_2$, water of metabolic origin, waste of vital activity (solid, obtained in urine, and volatile)—into free oxygen and full value food. In other words, ideal system of maintaining normal ecological medium in prolonged space flights should be carried out on the basis of completely closed rotation of substances, the principle of which is shown in Fig. 3.

If on spaceships it was possible to carry out such rotations of substances with necessary intensity during strict coordination of all processes and with their automatic adjustment, if all links of such a rotation could work stably and for indefinitely prolonged periods of time, then man would have possibility of accomplishing flights of any duration with installation on other celestial bodies or intermediate stations of bases for work for any given period of time. It is possible to say beforehand that complete solution of problem only by purely physical and chemical means is practically impossible, first of all because for obtaining of full value and variegated food from carbon dioxide, water and different organic wastes the most complicated chemical factory would be necessary, which man still does not know how to create even on Earth.

However, for solution of this problem there exist other ways—biological, which in combination with physical and chemical undoubtedly can be successfully used.

*This reaction can be useful as means of supply of system with oxygen from special reserves of water. However, because of necessity of having special reserves of water and difficulty of using hydrogen it can have value only in systems of limited time of action.

## Rotation of Substances in Nature

During attempt to solve this question we glance first of all at our own planet —how life of man is ensured and also necessary ecological medium for him and supply of food on surface of Earth. After all here people (and on Earth there are 3 billion of them) consume in the form of food huge quantities of organic substances and here they as a final result oxidize them into carbon dioxide and water. Work a few times larger in dimensions in this direction is conducted by highly and lowly organized animals. Still several tens or even hundreds of times more bacteria and mushrooms in process of fermentation and rotting oxidize organic substances. Huge quantities of organic substances (wood, peat, oil, gasoline, kerosene, alcohol, combustible gasses) are burned.

In addition to all this yearly into atmosphere of Earch are given off billion of tons of carbon dioxide, from it are absorbed and chemically combined billions of tons of oxygen, and thus it has continued tens, hundreds, thousands, and considering the age of Earth,—millions and even billions of years. However, atmosphere of our planet is not supersaturated with carbon dioxide (conversely, its content corresponds in all to 0.03 volume %), oxygen is not depleted (its contents is ~20%); on Earth organic substances are not exhausted and food for man and animals is not exhausted.

It occurs thus because on Earth, along with grandiose in dimensions processes of oxidation, combustion, and mineralization of organic compounds the not less grandiose process of their synthesis, new formation from simplest completely oxidized substances is accomplished. Various green plants, ground and water, large and microscopic accomplish it. This process is called photosynthesis.

Green plants assimilate from external medium carbon dioxide, water, and salts of nitrogen and mineral elements and form from them molecules of organic substances (carbohydrates, proteins, fats and others). This process is accomplished against drop of gradient of thermodynamic potential and requires expenditures on it of

energy from external source. Such a source is energy of sunlight (Fig. 4). Plants absorb it with the help of green pigment, chlorophyll, and it is directed to synthesis reaction of organic substances from completely oxidized simplest mineralized compounds. With this part of absorbed energy they store in the form of energy of chemical bonds in newly formed organic substances, which are used in processes of vital activity of the green plants themselves. Furthermore, they serve as food for infinite forms of heterotrophic, (i.e., fed only with prepared organic substances) organisms: animals and man, and also as substrata of vital activity for fungus and bacteria, most frequently in the form of dead reminders of plants and animals and, their waste materials.

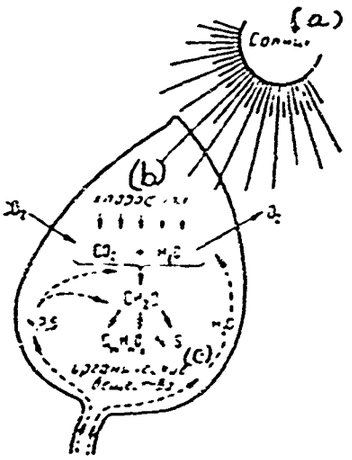



Fig. 4. Diagram of process of photosynthesis of plants, in which they (with help of energy of sunlight) from completely oxidized mineralized substances form various organic substances rich in energy.
KEY: (a) Sun; (b) Chlorophyll; (c) Organic substances.

All heterotropic organisms use organic substances obtaining food either directly from green plants themselves, or by means of intermediate links—animals, bacteria, and finally completely oxidize and mineralize them, again forming $CO_2$, $H_2O$, mineral salts, and thereby yielding food for green plants, which with the help of photosynthesis and energy of sunlight again start great cycle of substances and energy on Earth—cycle whose main links are, on the one hand, photosynthesis of green plants, and on the other—life of all organisms on our planet (Fig. 5).

Thus, life on Earth is supported on the basis of transformations of one and the same limited supply of chemical elements. But since they are in a constant closed cyclical rotation and are transformed in it an innumerable number of times, then existence of life on Earth can continue infinitely.

It is true that for this one indispensable condition is necessary--flow of energy from without. On our planet such energy is energy of solar radiation. It serves basic effective force of entire cycle of substances, and life on Earth will exist and be developed as long as the sun shines. In scale of duration of our life this will continue practically eternally.

In great cycle of life on Earth infinite types of living organisms participate. In totality they represent three basic groups, strictly connected among themselves.

First group is the group of autotrophic photosythesizing green plants, able primarily to create organic substances, combining in them energy of solar radiation and giving food and energy for life of all remaining organisms, including also man.

Second group is the group of animals, who directly or by means of more or less long food chains are fed by these organic substances and live owing to that energy which was absorbed and combined by green plants in process of photosynthesis. If we assess this group from the point of view of vital needs of man, then it is necessary to note that animals will so convert organic substances of vegetable origin that they in a number of cases turn out to be for man in food relationship the most full value, giving the most appropriate for the requirements of man proteins, fats and other substances important in physiological respect.

Finally, the third group comprises lowest heterotrophic plants--bacteria and fungus. They can live only on substrata containing prepared organic substances. One of the most characteristic peculiarities of these organisms consists in the fact that they can actively influence and subject to active chemical transformations not only those organic substances which turn out to be inside their bodies and living cells, but also substances of medium external for them on substrata. Micro-organisms influence these substances with the help of ferments and catalysts separated in external medium. Thus, literally being bathed in medium of organic substances and working with help of ferments, bacteria and fungus can extra-ordinarily fast be multiplied, process and finally subject to fermentation, rotting,

oxidation and mineralization huge quantities of organic substances. From point of view interesting to us now we must especially emphasize that in mass a group of these organisms is kind of sanitarian on surface of globe.

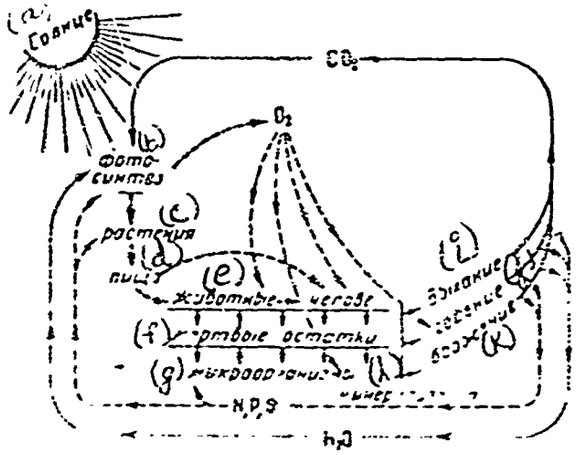


Fig. 5. Cycle of substances in nature. Effective force of cycle is energy of solar radiation, assimilated by green plants in process of photosynthesis.
KEY: (a) Sun; (b) Photosynthesis; (c) Plants; (d) Food; (e) Animals → →man; (f) Dead reminders; (g) Microorganism; (h) Mineralization; (i) Breathing; (j) Burning; (k) Fermentation.

They subject to fermentation and rotting colossal quantities of dead bodies, waste material and wastes of vital activity, clean surface of Earth from them and return chemical elements combined in them—first of all carbon, hydrogen, nitrogen, and phosphorus in a state available for feeding of green plants, and thereby repeatedly include these chemical elements in general rotation of substances. At the same time, such organisms, processing dead organic remainders or nonnutritive substrata, create biomass of their own bodies which in a number cases still can be valuable in food relationship (for instance, yeast).

It is clear that, using organisms of shown groups, it would have been possible to count on creation of full rotation of substances not only on scale of Earth, but also in limited closed spaces. Besides, of course there is no necessity of using all the types of organisms existing on Earth. It is necessary only to select the most active and suitable in each of groups and so to organize and coordinate their work that on the whole it ensures full cycle of rotation of substances, acting with intensity corresponding to intensity of vital activity of man and his needs.

Recently a great deal of attempts have been made to outline and create such rotations of substances for maintaining normal ecological medium in closed systems, with which man will be concerned in process of mastering cosmic space. We will

describe below some principles of creation of such systems.

## Problem of Regeneration of Air and Plants

Green plants in closed systems can be used for regeneration of air—absorption of $CO_2$, and production of $O_2$,—and in order to create food and fodder.

Let us consider possibility of use of green plants and photosynthesis for purposes of regeneration of air.

World of green plants is huge and includes millions of forms, possessing the most various biological, morphological and other properties. During selection of plants as possible participants of systems able to create closed rotation of substances, it is necessary to take into account a number of circumstances, of which the most important are the following.

1. Chosen plants must be characterized by the highest productivity, since during mastering of cosmic space, especially on spaceship itself and at intermediate and final stations, each superfluous kilogram of weight, each superfluous decimeter of area can be heavy burden.

2. They must be most suited for growth, vital activity and fulfillment of functions expected of them under conditions unusual for their "terrestrial" form of life; during weightlessness, possible strong vibrations, radiation influences, strong overloads in connection with possible sharp accelerations and decelerations of motion, etc.

3. Finally it is desirable, that these plants possess the greatest universality and be able to regenerate air well and to give the most full value food.

From the point of view of last requirement the most useful highly productive food and fodder agricultural plants, for a long time utilized by man and habitual for him. However, highest plants possess a number of properties making difficult the technology of growing them in conditions of space flight. They can normally grow in the presence of oriented gravity. Roots of these plants grow in directions

of its action, and stalk organs in opposite direction. In the absence of constantly oriented gravity it is impossible to obtain normal sowing, where all plants would grow together and with identical directivity and orientation of organs.

It is true, absence of definitely oriented gravity partially can be replaced by forces of chemotropism of roots and phototropism of ground organs: Roots strive to grow in direction of optimum concentration of food elements, and stalk organs in the direction of source of light. However, it is as yet unknown how completely these factors can replace absence of oriented gravity and, furthermore, light cannot be continuously acting factor: for normal and best growth of highest plants is necessary definite alternation for twenty-four hours of light and darkness in accordance with alternation of day and night on Earth, to which plants are strictly adjusted, possessing so-called photoperiodic reaction.

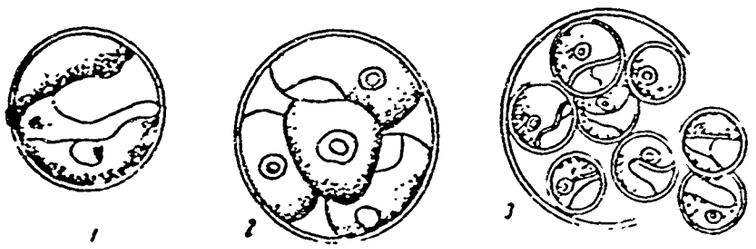


Fig. 6. Diagram of life cycle of Chlorella. 1—Young, intensely photosynthesizing, feeding and growing cell-individual; 2—all growing and preparing for reproduction; 3—cell forming eight autospores.

Besides this, highest plants possessing more or less long and relatively very flimsy stems and roots, probably will not be sufficiently sturdy to loads connected with high accelerations in active period of starting of spaceship, and sowings of them can be done only in stationary flight of ship or at intermediate stations, or in closed systems on other celestial bodies.

All this forced us to turn special attention to plants of other types. We consider unicellular green algae and in particular, Chlorella which is obtaining wide fame now. Each specimen of Chlorella, as also other algae from this group,

represents a unit cell, containing besides protoplasm nucleus and other organoids peculiar to living cells, also green body chromatophore (Fig. 6). Chromatophore contains green pigment chlorophyll, peculiar also to other green plants.

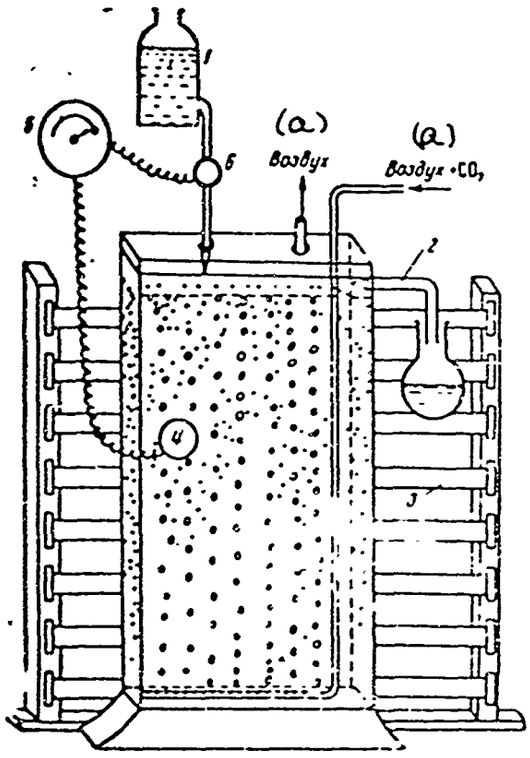



Fig. 7. Flat chamber of plexiglas with suspension of Chlorella, ventilated by air with $CO_2$ and illuminated by luminescent lamps. 1—Vessel with nutrient medium for enrichment of suspension after sampling of portions of suspension; 2—Overflow faucet of suspension for collection of biomass; 3—luminescent lamps; 4, 5, 6—system of instruments for automatic maintenance of density of suspension at optimum level (4—photocell, 5—amplifier, 6—actuating mechanism).
KEY: (a) Air.

Because of the presence of chlorophyll, aqueous medium containing Chlorella cells is a green suspension, able to absorb intensely the energy of solar radiation. If suspension of cells is illuminated well and is supplied with carbon dioxide by means of blowing air containing $CO_2$ through it (Fig. 7), and if in water there are necessary nutrient salts containing nitrogen, phosphorus, potassium, sulfur and other elements, then Chlorella cells in suspension can carry out intense synthesis and energetically form organic substances, owing to which their growth occurs (Fig. 8). Reaching definite magnitude, cells pass into following phases of development: contents of cells are divided into several parts—autospores (2, 4, 8 and even 16, depending on activity of form and conditions of its feeding).

When autospores are formed, shells of maternal cell burst and autospores, representing daughter cells rich in chlorophyll and ready for intense photosynthesis, turn out to be in liquid medium and, if for this conditions are good, they start intense photosynthesis, rapidly increasing in dimensions, so that they again grow,

form autospores and again give up to 4-16 daughter cells. Each life cycle for Chlorella continues near twenty-four hours, but the most active forms are able to reproduce every 8-6 hours, i.e., to have up to 3-4 cycles in twenty-four hours.

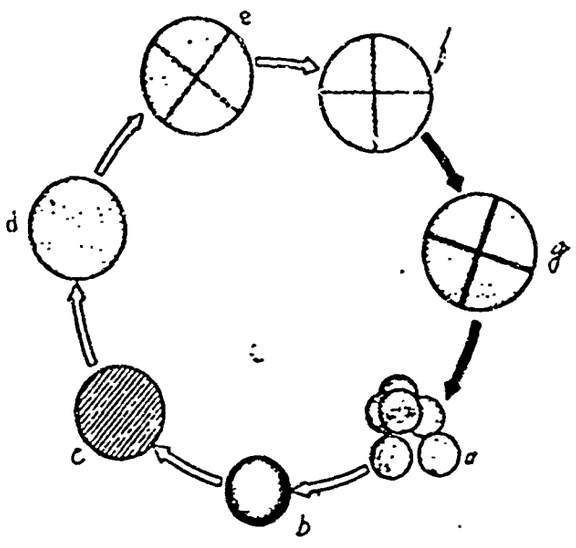



Fig. 8. Cycle of growth, development and reproduction of Chlorella cells. a—Just now formed daughter cells; b,c—Young fast growing cells, rich in chlorophyll and possessing high activity of photosynthesis: d, e, f, g—Mature cells in stage of preparation for formation of autospores (content of chlorophyll and photosynthetic activity for them is lower). Light pointers—stages for occurrence of which light is necessary, black—for which light is not obligatory.

In favorable conditions, even if each cell gives on the average 4 autospores, in twenty-four hours one initial cell can generate 64 cells and correspondingly increase biomass 64 times, creating it from $CO_2$, $H_2O$ and elements of mineral salts. However, similar indicators of relative photosynthetic rate of reproduction and buildup of biomass can be observed only in suspensions of low density, containing very small number of cells (less than 2 million in $1cm^3$ of liquid). Such suspensions comprise almost completely transparent, light greenish liquid. In it all cells are well illuminated, and competition between them for light, carbon dioxide and elements of mineral feeding is minimum. This also gives each of them possibility to photosynthesize and be multiplied with maximum intensity.

With reproduction of cells and increase of density of suspension their illuminance worsens, and competition between them for nutritive elements increases; therefore intensity of their photosynthesis is strongly lowered and multiplication factors of cells drop (Fig. 9).

In good conditions density of suspension can reach very high magnitudes—1-2 billion cells in 1 $cm^3$. However, cells in such suspensions are badly supplied with

light and food. Photosynthesis with this hardly balances and hardly compensates breathing of mass of cells and their natural dying off; density of suspension and its biomass finally cease to grow.

Absolute photosynthesis and twenty-four hour buildup of biomass are small also in suspensions of low density; relative multiplication factors of cells here are also large, but concentration of them is so small that even quadruplicating or decupling their number cannot give significant absolute increases (see curve 3 in Fig. 9). Thus, decupling in 24 hours of cells in suspension with density of 2 million cells per 1 $cm^3$ will give absolute increase in all of 18 million cells in twenty-four hours. Increase of number of cells only 2 times with density, for instance of 600 million cells, can given twenty-four hour absolute increase of 600 million cells.

Thus, for each form of algae (depending on its activity) and for one or another combination of conditions of illumination, of supplying with carbon dioxide and mineral food, there is optimum density of suspension at which absolute twenty-four hour photosynthesis (i.e., absorption of $CO_2$ and liberation of $O_2$), and also intensity of buildup of biomass turn out to be the highest. It is necessary to select such conditions when optimum concentration of suspension would correspond possibly to higher density of it and with this possibly higher coefficients of twenty-four hour reproduction of cells were kept, which gives the highest yields of photosynthesis and twenty-four hour increase of biomass. If from suspension of optimum density a definite portion is removed, let us assume every 6 hours, in which there is contained so many cells, how many of them will be formed anew in 6 hours? And if biomass is separated from it (for instance, by means of centrifuging), and liquid is returned to reactor and there are added nutrients in quantities, corresponding to removal of them by cells, then a kind of engineering-biological system can be obtained, which continuously and stably with identical intensity will absorb $CO_2$, liberate free oxygen and form organic biomass.

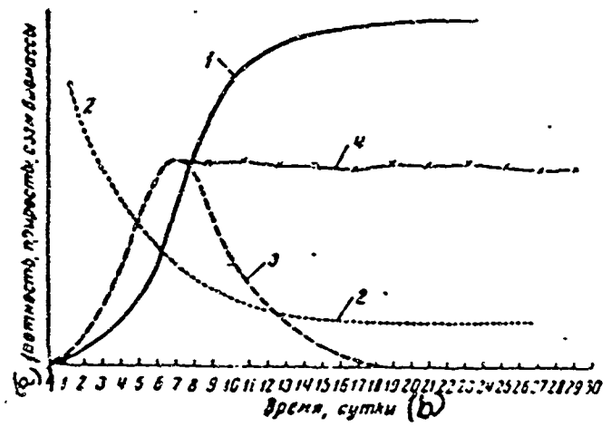


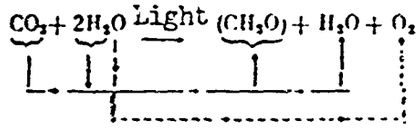

Fig. 9. Change of properties of suspension of Chlorella with growth in it of number of cells. 1—Density of suspension; 2—Twenty-four hour multiplication factors of cells; 3—twenty-four hour increases of number of cells and of dry biomass per 1 l of suspension; 4—course of sampling of harvest of biomass with maintenance of density of suspension at optimum level (automation). KEY: (a) Density, increases, diagram of biomass; (b) Time, twenty-four hour periods.

Continuity and uniformity of action of such a system is one of its very important advantages over system with participation of highest plants. The latter in twenty-four hours require period of darkness and during this time not only do not produce oxygen, but consume it moreover, giving off $CO_2$ into air. Furthermore, highest plants have in one or another degree sharply expressed seasonal periodicity of vital activity; for them is characteristic period of germination, when they form seedling, on the whole having small surface of leaves and badly absorbing energy of light. Nonetheless sprouts for good growth require very intense illumination. In these conditions completing period of vital activity of highest plants is disadvantageous—period of formation and ripening of reproductive and storing organs (grain, fruits, root crops, tubers, bulbs), when area of leaves strongly decreases, and photosynthesis drops. However, for obtaining normal harvest plants must still remain in place, since there important processes of movement of substances, and deposit of them in storage occur which is connected with obtaining of harvests of necessary quality.

As we have seen, for unicellular algae such a periodicity is absent and their culture can produce continuously for indefinitely long time. Besides this, unicellular algae give uniform biomass, convenient for use as fodder or as food and not divided, as for highest plants, into food or fodder and wastes (straw, stems, roots, vegetable tops, etc).

If we still consider that Chlorella cells do not have polarity, that they do not have fixed orientation in space, but are freely suspended in aqueous medium and do not need action of definitely directed gravity, that at last, being in aqueous medium, they are not so subject to negative action of accelerations, vibrations and change of pressure and temperature conditions, then it will become clear that unicellular algae are the most convenient autotrophic organism for use during mastering of cosmic space and first of all for regeneration of air.

Moreover, as a result of photosynthesis the culture of algae can absorb $CO_2$ formed by man in process of breathing, given off free oxygen and decompose metabolic water, liberating its oxygen in free form and using hydrogen for restoration of $CO_2$ and formation of organic substances.




Theoretical calculations talk about the fact that need of man for oxygen and transformation of $CO_2$, and metabolic water formed by him into full value products can be ensured by cultivation of Chlorella in suspension with volume of approximately 20 l. Thus, problem of regeneration of air in prolonged space flights most profitably of all is solved by use of intense culture of unicellular algae. Along with this they give biomass which can be used as food or as animal fodder.

## Guarantee of Man with Food

If unicellular algae gave full value food for man, then ideal closed system could be system of two components.

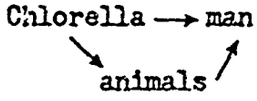
algae $\rightleftarrows$ man.

However, it is now impossible to count on the fact that biomass of Chlorella can be only food for man, first of all because although it is very rich in proteins

(up to 40-50% counting on dry weight), these proteins are not, from the point of view of man, completely full value.

Probably, in ration of man in space flight it will be necessary to introduce in some part (for instance up to 25%) animal proteins. Proteins of Chlorella, which readily is eaten by animals, certain fish, a number of vertebrates and, finally by hens and rabbits, can be transformed into animal proteins. Thus, necessity appears to include certain animals in system of guaranteeing man with food in space flight. The most promising in this respect are certain herbivorous fish, small animals with short cycles of development, rapidly reproduced (for instance, rabbits), and especially animals giving not only meat, but also alienated food products (eggs, milk). Utilization factors of fodders on formation of just such alienated products usually are the highest.

However, even a three-component closed system could not satisfy food needs of man completely.




The fact is that in normal food ration of man there should be near 400 g of carbohydrates (large part of them in the form of starch), 100 g of proteins and 100 g of fats. However, in composition of biomass, intensely cultivated and well supplied with nitrogen of Chlorella, the ratio of these components is quite different; in it there is contained near 40-50% of proteins, 40-30% of fats and in all 10-20% of carbohydrates.

During feeding of biomass of Chlorella to animals they, intensively consuming carbohydrates, would give food still poorer in carbohydrates, which is clear from data of Fig. 10.

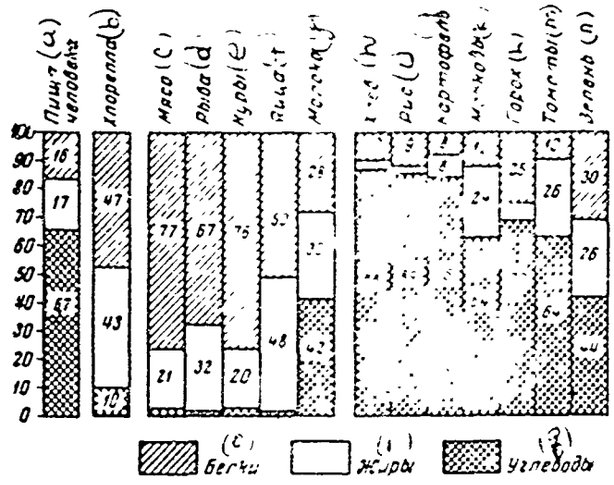


Fig. 10. Carbohydrates, proteins and fats necessary for normal feeding of man and available in different food products. KEY: (a) Food of man; (b) Chlorella; (c) Meat; (d) Fish; (e) Chicken; (f) Eggs; (g) Milk; (h) Bread; (i) Rice; (j) Potatoes; (k) Carrots; (l) Peas; (m) Tomatoes; (n) Greens; (o) Proteins; (p) Fats; (q) Carbohydrates.

Food rich in carbohydrates usually is given by highest plants and first of all in reproductive and storing organs. Furthermore, many of them contain high-quality proteins, for instance grain of wheat, potatoes, grain of leguminous plants and others. Highest plants give many products with good taste qualities (vegetables, fruits), and also containing stimulating substances (onion, dill, parsley, etc).

All this forces us to consider that necessary components of closed systems for mastering by man of cosmic space must also include some thoroughly selected highest foodstuff plants, especially counting on their use at intermediate stations, and in closed systems of other cosmic bodies (Moon, planets, etc).

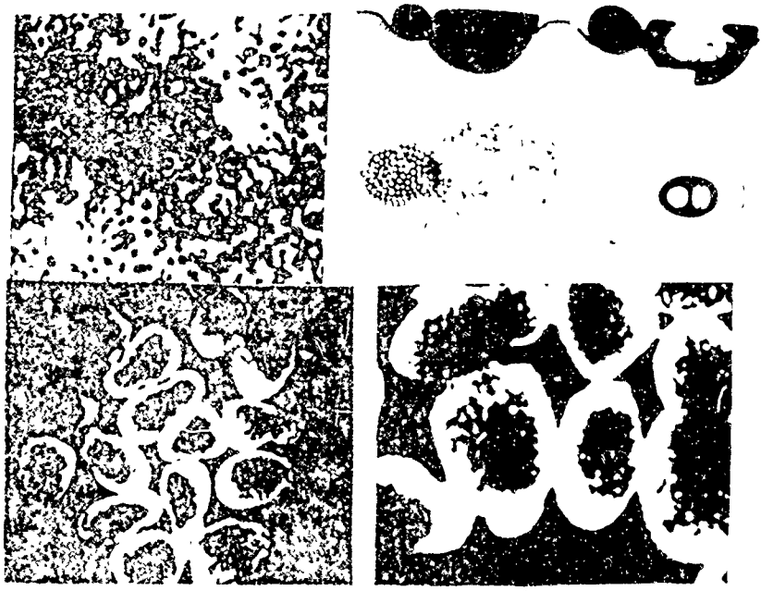


Fig. 11. [illegible] arrhiza (rich in starch), flowering [illegible] (dimension of plant 0.2-1 mm). 1--cross section of [illegible], vegetative body with bud--on surface [illegible] conspicuous; 2--cross section of blooming [illegible] and stamen--buds are conspicuous [illegible] (by authors).

Considering difficulties of growing highest plants, about which we spoke above, it is necessary to be concerned especially thoroughly with selection and type of their culture. Probably in order to be able to cultivate highest plants on spaceship or intermediate station, it will be necessary to compensate absence of gravity by artificially created centrifugal forces and spatially directed action of light and nutritive salts.

It is very important to select for culture floating water plants. For instance, in biomass of very small in dimensions water plant--Wolffia (Fig. 11), judging from data of Japanese scientists, is stored up to 60-65% of carbohydrates in the form of starch.

Perennial plants, which can vegetate continuously can be convenient in culture, and also plants which can be exploited by means of continuous collection from them of harvests in the form of leaves (stimulating and tasty salad plants), and tubers (for instance, sweet potato). Continuity of vegetation of these plants can be ensured, creating by it corresponding conditions of feeding and illumination, also by means of surgical influences (pinching, pruning, collection of harvests).

Thus, by clever and rational selection of algae, highest plants and animals it is possible to create microcosm in cosmic space which will ensure regeneration of air, supply of food and create for man a setting in some degree customary and satisfying his aesthetic and psychological reactions and needs.

## Problem of Liquidation of Waste and Regeneration of Water

However, the above-mentioned questions do not exhaust all that is necessary for creation in flights of normal ecological medium for man. So that this occurs on the basis of full rotation of substances, it is necessary to solve properly the problem of liquidation of waste and involvement in rotation of chemical elements contained in them. Waste in closed systems will be excrements of man and animals, their urine and substances dissolved in it, volatile substances given off by man and animals through lungs, skin and from wastes, finally, this will be wastes from

use of products of "animal husbandry", "pisciculture" and "plant growing", dead remainders of plants (dry leaves, withering rootlets), eggshells, scales of fish, feathers of birds, bones of all animals, etc.

For liquidation of waste two different principle ways are possible. One way is biological, where wastes of vital activity of some organisms can be used by others, for instance urine and substances contained in it (urea, mineral salts), and also partially solid excrements by Chlorella and, partly, by highest plants with this can be solved triple problem: 1) useless and even harmful wastes will be liquidated; 2) in exchange for them full value biomass of algae or plants will be created; 3) contaminated water of urine will be evaporated by plants or from suspension by algae to be condensed, and thus the problem of regeneration of water will be partially solved.

Some wastes can be liquidated with the help of animals; eggshells, bonemeal, processed viscera and feathers can be fed to birds. In principle part of wastes can be processed with help of microorganisms, as this occurs on a huge scale on Earth.

However, this is a complicated process and for liquidation of part of wastes (which can't be used by Chlorella, highest plants and animals) it is expedient to use alternate way--chemical with extraction from wastes of useful components (NaCl and nitrogen containing substances) with subsequent burning of remainders and obtaining of $CO_2$, $H_2O$ and ashes. The latter can be used by plants.

The most difficult problem in this case can be liquidation and involvement in rotation of volatile substances--final products of vital activity which, spreading rapidly in atmosphere of closed system, can contaminate water (being dissolved in it), be adsorbed by food and on surface of all objects of ship or closed system and depart from sphere of possible participation in rotation of substances. However, problem of liquidation of these wastes also is not insolvable.

## Concerning Nitrogen Cycle

In the course of a number of biological processes, and also during burning of organic substances of wastes, nitrogen combined in organic substances and accessible for biological transformations can pass into gaseous state and depart into atmosphere. Nitrogen--gas is inert and in this state is inaccessible for biological use to overwhelming majority of organisms, including man, Chlorella, majority of highest plants, and animals.

In the absence in system of inverse process, i.e., process of binding gaseous nitrogen and transfer of it into composition of salts and organic substances, it can finally all or in large part change into gaseous state, and life in closed system cannot be maintained.

In nature on Earth binding of gaseous nitrogen occurs in various ways. Certain bacteria are able to do this--tuberous bacteria of leguminous plants, free living nitrogen-fixing bacteria, such as Azotobacter and others--also blue-green algae, which along with photosynthesis carry out also binding of gaseous nitrogen, introducing it in final count into composition of amino acids and proteins necessary to it for life. These organisms--especially blue-green algae--can be used also in closed biological systems in space flights. However, along with this can be used also direct oxidation of gaseous nitrogen in electric discharge of arc or at high temperatures. With this oxides of nitrogen are obtained, and then salts of nitric acids, accessible for feeding of Chlorella and highest plants.

## Power Supply of Closed Cycle of Rotation of Substances

So that full rotation of substances in closed systems of space flight could be carried out, it is necessary to supply it with energy and, in particular, to compensate energy transformed into heat and dispersed into environment, and liberated during breathing of man, animals and plants. "Gate", through which in closed cycle

energy can and should be introduced is photosynthesis of algae and highest plants. Form of energy necessary for this is energy of light.

Light can be natural, solar, or artificial, but as far as possible close to spectrum of sunlight.

Thus, entire system for its continuous and proper functioning should continuously be supplied with light energy.

* * *

Thus, as a result of reasonable selection and strict coordination of work and vital activity of autotrophic and heterotrophic organisms, combining them with physical and chemical methods and with guaranteed reserves of food and oxygen, man can create system of full rotation of substances (Fig. 12), which will ensure him normal ecological medium for his time of stay in cosmic space for any period of time.

Composition, content and technical means of realization of these systems can be the most diverse. Depending on assignment, on necessary duration of their action, on place of use (ship in flight, intermediate station, hermetically sealed or even open systems on other celestial bodies), they can include different components.

On short flights they can be semiclosed (for instance, only with cycle for regeneration of water, and in other respects working on reserves). On prolonged flights in ship they must be completely closed, but with minimum necessary set of living organisms, among which nevertheless an indispensable participant will be undoubtedly algae. Where this is possible, in these systems must be maximally used physical and physicochemical methods, which are especially expedient in operations on regeneration of water, burning of wastes, binding of nitrogen and others.

At intermediate stations and on other celestial bodies there must be systems with wide set of organisms, which could completely satisfy the most various requirements of man for composition of atmosphere and food and ensure him proper

esthetic and psychological setting. At the same time, there must be systems working reliably, automatically monitored and controlled, with maximum use of principle of self-regulation.

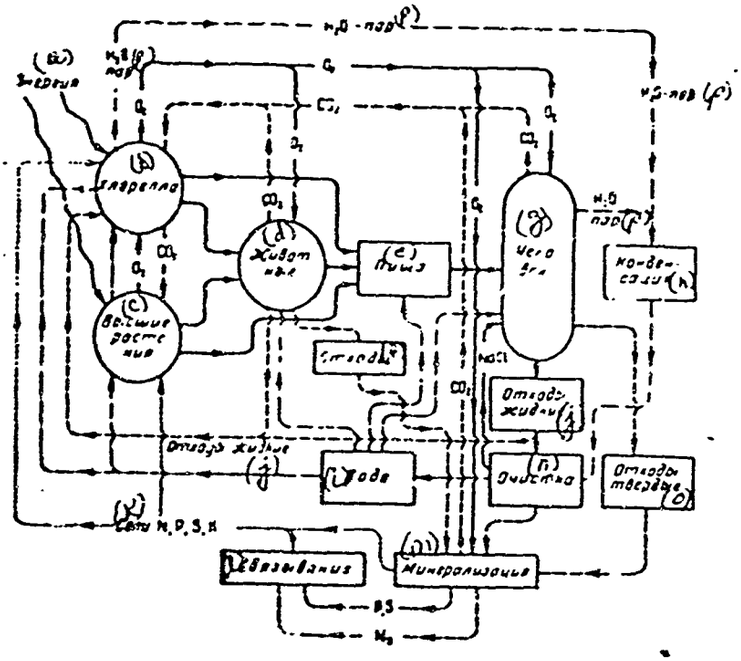


Fig. 12. Example of possible diagram of full guarantee of man in space flight with food, oxygen, and water on the basis of full rotation of substances with use of autotrophic and heterotrophic organisms and physical chemistry methods. KEY: (a) Energy; (b) Chlorella; (c) Highest plants; (d) Animals; (e) Food; (f) Wastes; (g) Man; (h) Condensation; (i) Water; (j) Liquid wastes; (k) Salts; (l) Binding; (m) Mineralization: (n) Purification; (o) Solid wastes; (p) Vapor.

Composition of these systems should change in connection with more precise definition of requirements with which man can be reconciled and with those which must be unconditionally satisfied. Thus, we conducted all the above-mentioned calculation, proceeding from those requirements in food and oxygen which are fixed for man in his normal "terrestrial" life.

However, range of adaptable possibilities of man and even of other organisms is very great, and this human ability must be used in full measure during designing and realization of future closed systems. Besides it is necessary not to forget

that on Earth there are complete vegetarians, and people fed almost exclusively on fish and food of animal origin (inhabitants of Arctic zone).

Furthermore, we by far still do not completely know potential possibilities of all representatives of vegetable, animal and microbe world or our planet. Here intense searches and tests are necessary. And maybe in future, when adaptable possibilities of man and potential possibilities of representatives of various groups of vegetable and animal kingdom of our planet and finally, colossal possibilities of physics, chemistry, and technology are maximally used, then systems of guaranteeing man on the basis of full closed rotation of substances will be significantly simpler than those which are described above.

However, even now there already exists knowledge, organisms, and technology which give possibility to work on creation of such systems, in order to use them already in near future and to improve them subsequently.

Man will head into cosmic space not on amusement jaunt, but for serious and intensive work. Therefore, he should arrange in cosmos conditions of maximum safety and maximally accessible conveniences and comforts in this situation. Our contemporary knowledge indicates that this is a fully soluble, although by far not easy task.

Already ways of its solution are clear, and circumstances require intensive work in this direction, so that solution of technical and biological problems of mastering by man of cosmic space proceed synchronously, and technical possibilities of space flights simultaneously are reinforced also by possibilities of solution of biological problems. One of the most important and responsible of them is the problem of guaranteeing man a normal ecological medium on the basis of full rotation of substances accomplished with participation of autotrophic—photosynthesizing and heterotrophic organisms.

# ASTRONAUTICS AND EXTRATERRESTRIAL CIVILIZATIONS

V. I. Krasovskiy

Recent years were marked by huge successes in mastering of space . Prolonged flights of Yu. A. Gagarin, G. S. Titov, A. G. Nikolayev, and P. R. Popovich on artificial satellites, completed by their safe return to Earth, were remarkable historical events. It was proven that man can preserve normal vital activity in conditions of space flights. Now more prolonged space journeys and even visits of extrateresstrial worlds are practicable. At the same time contemporary achievements in area of rocket technology put at disposal scientists absolutely new means for exploration of upper atmosphere and cosmic space. With their help already significant results have been obtained and still more significant ones are expected. It is not surprising therefore that recently interest in many problems of mastering of space has strongly increased.

How far will mastering of extraterrestrial spaces proceed? What are its targets, practical value? Do life and highly developed civilizations exist on other worlds? Is communication with them possible? Is it impossible already and now to receive any intelligent signals? Hasn't Earth been visited by space travellers? For the last decade many captivating fictional novels have been dedicated to these questions and many of them obtained wide popularity. However, now it is already possible to give scientifically proved answers to these questions,

based on contemporary ideas of possibilities of human civilization, of plurality of life in universe and absurdity of human geocentrism.

Still in 1600 inquisitors burned at stake Jordan Bruno for his bold expressions about plurality of inhabited worlds. And at the end of past century, when theory of relativity still was not formulated, our compatriot K. E. Tsiolkovsky began to develop on a scientific basis a theory of space flights and mastering of extra-terrestrial space. "I believe in the brilliant future of humanity" he wrote; "I believe that humanity not only inherits Earth, but also will transform world of planets. Hence, from sphere of Sun settling of man in universe will begin. Of this I am deeply convinced. This is the lot of terrestrial man. He should transform many planet systems". In his book "Dreams about Earth and Sky", written in 1895, K. E. Tsiolkovsky sketches picture of settling of people around sun, between Earth and Mars, on artificial cosmic bodies, screening Sun for full use of its huge energy (now in vain squandered by it in cosmic space surrounding us). Analogous idea at present has currency abroad. ...Civilized living organisms, striving completely to master stellar energy, create around star artifical inhabited shells. Radiation of star, having temperature of several thousands of degrees, heats shell to comparatively small temperature, favorable for vital processes, with which bodies radiate thermal infrared radiation invisible to the naked eye. If theory is true, then existence of such living organisms can be observed on powerful infrared stars.

However, it is necessary nevertheless to say that there is real basis for such bold ideas, but all the more so realization of them pertains to far future. At present study of space is only in the most beginning stage. With every year much new will be learned. And although not all that which is noticed in nature turns out to be immediately intelligible and is packed into ideas formed, nevertheless technical possibilities of exploration of space are uncontrollably expaned. Then, that about which Tsiolkovsky only dreamed, in our time gradually is becoming reality.

Fantasy frequently outstripped development of science and technology and even promoted it, if it was scientifically proved. It is completely natural that some forecasts were justified, and others appeared unfounded. However, at present mastering of cosmic space scientifically is fully substantiated, in spite of the fact that some more distant stages of it still are not finally clear.

In connection with increasing need to obtain convincing answers to questions touching cosmic subjects, numerous hypotheses appear and facts are sought for their proof. Unfortunately, in many cases time still has not come for exhaustive answers to all "cosmic" questions, and sometimes even for their full formulation. Therefore it is necessary to be limited to short discussion in connection with some subjects interesting to us.

No one doubts that soon spaceships controlled by astronauts or supplied with improved automatic equipment will ensure carrying out of more complete exploration of solar system. Numerous large and small artificial earth and sun satellites will appear and also scientific stations on Moon and Mars. All this will have not only purely theoretical value. New means will make possible systematic observations of solar activity, interplanetary medium, temperature and cloud cover of Earth. Information about this is necessary in order to ensure regular radio communications and weather forecast. With help of artificial satellites relaying over large distances of ultrashort radio waves, and consequently also of television will be carried out, and capacity of chanrels of long-distance communication essentially will be increased. Artificial satellites will become reliable beacons for naval, air and cosmic navigation.

One should not forget that dark forces try to direct these means to military purposes. However people of good will trust that reason triumphs and mastering of cosmos will proceed only in peaceful direction.

Till now in most cases satellites and space rockets were used, carrying various equipment for exploration of upper atmosphere and cosmic space. Data obtained with help of such instruments were transmitted to Earth by means of

radiotelemetry. As a result of conducted investigations, fundamental scientific discoveries were made. However, similar methods do not give possibility of obtaining all the necessary information about various properties of cosmic space and its objects. They become especially little effective, when explorations are conducted at great distances from Earth. The deeper the exploratory spaceship penetrates into cosmos, the more difficult is its technical implementation. For guarantee of reliable communication, able to transmit in these conditions the obtained information from aboard the spaceship to Earth, more and more powerful radio sets and antenna are required. To place them in such a comparatively small construction is very difficult, and observation of work of scientific research laboratory from Earth becomes difficult. Therefore, it is more expedient to send research ships with equipment which records its own measurements on photographic materials or tape recorder tapes, later returned to Earth. Such a method possesses a significantly greater informativeness than transmission of data with help of telemetering equipment. It already partially was used when from some satellites special containers were dropped to Earth.

This method will be enriched still more if together with equipment man will set forth on journey. He will be able then by his own discretion to regulate and to carry out program of exploration in accordance with local conditions, taking into account results of his measurements, which could not be foreseen until direct penetration into depth of interplanetary space.

It is difficult to describe all important scientific undertakings which can be carried out with the help of such a spaceship. They include first of all detailed explorations of Moon and planets with delivery to Earth of the most essential exhibits. This is necessary in order to study processes of formation of planets, and consequently also of Earth, in bowels of which people detect necessary mineral products for it. Apparently, only such explorations will be presently effective for solution of puzzle of life outside Earth in past and present time.

Space flights of Yu. A. Gagarin, G. S. Titov, A. G. Nikolayev, and P. R. Popovich are first significant landmarks in history of technical realization of such aspirations.

Not less essential is the construction of scientific stations on moon and other planets. Enumeration of all the important problems whose solution is expected with the help of such means would occupy much space. Therefore, we will be limited only to examples from one area. Astronomers studying space are deprived by terrestrial atmosphere of possibility of conducting observation in all sections of spectrum of cosmic radiations, including also range of usual radio waves. Moreover, even in usual optical region the instability of atmosphere hinders obtaining of good optical images of extraterrestrial objects. Radioastronomers use twin radioantennae with very large base (interferometers), increasing thereby resolving power of equipment, but finite dimension of Earth and distortions introduced by atmosphere here are also fundamental barriers. Scientific stations on moon, on satellites of other planets and asteroids (on which there is no atmosphere) permit to observe in all sections of range of electromagnetic waves, including also in radiorange in the absence of atmospheric radio interference. Furthermore, twin radioantennae on various objects in outer space, connected among themselves with help of radio communications, will be able to ensure radio reception system with indeed grandiose resolving power, inasmuch as for this purpose it will be possible to select objects in outer space at very great distances from each other.

At present, idea about plurality of life in universe in principle is not considered; as in times of the Middle Ages it was sedition, now negation of this idea more quickly causes wide protest. Nevertheless, when concrete judgements on this matter are concerned, among specialists special attitude concerning the question usually predominates or, in any case, tendency to deviate from positive answers. This is explained by insufficiency of necessary information in many areas of science.

Contemporary data on physicochemical state of planets of solar system obtained with help of ground means of observation, in most cases do not allow existence on them not only of animal, but also of vegetable life. Apparently, only on surface of Mars is some primitive vegetation like lichens or microorganisms possible. However, quite recently some information about Mars, for instance about its "canals", gave cause to assume existence there of reasonable creatures. Still up to the present many mysterious phenomena on Mars remain unexplained and give bases for hypotheses about reasonable life in past. For instance, Professor I. S. Shklovskiy paid attention to anomaly, long known and causing doubts till now which consists of continuous decrease of period of revolution of Martian satellite (phobos). As is known, similar picture is characteristic also for artificial earth satellites. This occurs because even very rarefied atmosphere at large distances from Earth is sufficient for their braking. On the basis of conspicuous analogy it was completely natural to assume that phobos also decreases period of revolution around Mars for the same reason. This led to conclusion that its average density is small, i.e., it is hollow. Calculations conducted then showed that phobos could appear in area of action of Martian gravitation only several hundred million years ago and in near future will fall onto surface of planet. Inasmuch as contemporary cosmogony assumes that Mars was formed several billion years ago, and does not consider possible the appearance for it of satellites in later time, I. S. Shklovskiy assumed that phobos is artificial satellite, launched by now extinct highly developed reasonable Martians. For final solution of question a check of anomaly on basis of more contemporary observations is necessary.

Meanwhile, in some popular articles and lectures it was reported that Martian satellites appeared not several hundred million years ago, but quite recently -- in middle of past century, inasmuch as till then they were not observed by experienced astronomers, using powerful telescopes. In connection with this it is necessary to remember all circumstances having relation to two satellites of Mars. For the first time they were mentioned in 1726 in novel of Jonathan Swift, "Gulliver's

Travels", and not in scientific literature. Reported data accurately correspond to what was reported much later reliably by astronomers observing them. Swift does not report the source of his information. However, he was contemporary of physicist Torricelli, who is famous as unexcelled at that time master of manufacture of optical lenses of very high quality. Torricelli could see in his instruments the satellites of Mars, and this information could reach Swift, although in those years technical formulas were kept in deep secret. Contemporaries of Torricelli, and even later masters, could not manufacture perfect optics. Decisive success in this direction was reached only in middle of past century, and then satellites of mars turned out to be accessible for observations with help of small perfect instruments. Consequently, reports about appearance of satellites of mars only in past century are caused by ignorance of history of question.

But in general could there exist on Mars sometime earlier a highly developed civilization? For characteristics of status of knowledge in this area we will remember two hypotheses of origin of planets. According to the first, they were formed as a result of condensation of vapors of heated matter. Every planet in the beginning had very high temperature. Appearance of life was possible only after cooling of surface to several tens of degrees Celsius. Due to smaller dimensions, Mars could cool earlier than Earth. Therefore, also life on it could appear earlier and outstrip terrestrial by hundreds of millions and even by a billion years. However, later favorable conditions for its existence were lost completely. Because of insufficient gravity Mars fast lost such necessary for life gasses as oxygen and water vapor.

Another picture is sketched by another hypothesis. Its supporters consider that planets appeared as a result of joining during collisions of cold metorites. In this case initial temperature of planet was low, possibly even lower than zero degrees Celsius. Only later could it be somewhat increased because of radioactive processes and owing to compression of separate conglomerates of metorites under

influence of huge gravity. Thus, temperature of mars only now, or quite recently, was increased to values necessary for appearance of primary living organisms, primitive plants and microbes. Regarding, Earth however, then it was heated earlier, inasmuch as its mass is greater and it is nearer to sun. These circumstances also led to earlier and more rapid development of life on Earth.

At present different hypotheses animatedly are discussed and still here isn't any generally accepted view on origin of planets. As essential arguments in favor of first hypothesis serve such planets as Jupiter and Saturn. Their predominant element is hydrogen. It does not enter into composition of meteorites, from which, according to the second hypothesis, planets could be formed. It seems very incredible to assume that various planets appeared in various ways, as a result of different not mutually connected circumstances. It is more natural to assume that the entire solar system was formed simultaneously as a result of single process. Contemporary cosmogony is still not a summary of reliable knowledge. It remains still in stage of searches and tests of different hypotheses, in each of which can be found something vague or doubtful. Therefore, at present it is impossible to give final simple answer to the question posed.

However, if we prove that in past there existed on mars conditions for appearance of reasonable creatures, then it will become possible to make more definite conclusions about their contemporary fate. In order to clearly present possible in this case situations on Mars, let us look at what could occur on our Earth during any threat of grandiose cosmic disaster, able to destroy atmosphere and life on surface. Humanity at contemporary stage of development already is in state of struggle not only with usual spontaneous disasters; it is capable of even more. At present there are technical possibilities for creation of extensive underground airtight refuges, supplied by reserves of compressed air, water, and sources of nuclear energy, where favorable artificial climate and illumination can be maintained and vegetation necessary for food and regeneration of oxygen from

carbon dioxide can be cultivated. It is completely possible that in the very near future successful development of chemical technology will ensure obtaining of nutrients formed at present in plants as a result of photosynthesis owing to solar radiation. Then new possibilities of realization of underground life will appear. Regeneration of oxygen from carbon dioxide also can be carried out as a result of special artificial technology without use of plants. In places of habitation of living organisms it will be possible significantly to decrease radioactivity and to create conditions for greater genetic stability, i.e., for protection from degeneration caused by harmful influence of products of radioactive decay.

It is incredible to assume that people will refuse to do all this if they know reliably about catastrophe for tens, hundreds or thousands of years. Apparently, possessing powerful power and technical resources, they will be able to cope also with destructive perturbations in Earth's crust, connected with its grandiose tectonic motions, and other processes which already have destroyed majority of traces of primitive life. It is obvious that just so Martians would proceed also (of course, if they existed), they waited to be destroyed on surface of planet. One should remember that surface of Mars has quite smoothly changing relief. This indicates the absence of intense orogenetic processes, and consequently also more favorable conditions of existence inside crust of planet.

Actual Martians, if they exist, could easily at present establish the presence on Earth of civilization starting stormily to be developed with help of radio reception, passing through ionosphere in large solid angles of terrestrial radio wave radiation, from radio stations, radio beacons, television stations and interferences of electrical origin. Incidentally, contemporary terrestrial radio communications is too wasteful from power point of view. Already now there are created more economical and more informative narrowly directed cable-waveguide lines. Apparently, as a result of further progress on Earth there will remain only such a perfect and economical system of radio communications without useless radiation of

radio waves in space surrounding us. It probably exists also on mars, if highly developed Martians live there.

If, however, contemporary Martians live inside planet, then why do they not make themselves known, for instance, by means of some special radio signaling? Need for self-announcement, if it is indeed inalienable property of reasonable creatures, perhaps is satisfied only with possession of surpluses of power resources. It is necessary not to forget the fact that even if Martians are occupied in self-announcement by radio, we can not know about it, inasmuch as in general regular observations of Mars and all the more so in all sections of range were not conducted and are not being conducted.

For solution of puzzles of Mars further scientific explorations are necessary, including some with help of astronavigation. However, fantasy outstrips possibilities. Fiction writer A. Kazantsev in novel "Guest from Space" tries to convince readers that Martians already made themselves known by nuclear or thermonuclear explosion, which is perceived in phenomenon of Tungus meteorite. In fall of Tungus meteorite there are indeed many mysterious circumstances. Study of them continues, and now there are not any scientifically founded proofs of the fact that this phenomenon was caused by nuclear or thermonuclear explosion.

In many foreign fictional novels extraterrestrial civilizations make themselves known first of all either by barbarous sudden attack on Earth, or by terrible bombardment of it. But it is strange to assume that highly developed civilizations, imitating morals of authors of such novels, start acquaintance with their neighbors namely by means of senseless bombardment of them, for instance with nuclear and thermonuclear bombs. In any case it is more natural to expect that extraterrestrial highly developed civilizations will appear more humane and reasonable than authors of terrible fictional novels.

According to contemporary research of radio emission of Venus, its surface has very high temperature, several hundreds of degrees Celsius. This circumstance makes impossible the existence on Venus of any life. However, recently Professor

A. N. Kozyrev expressed assumption about presence of primitive life on Venus, considering that very high radiotemperature of Venus is created by its ionosphere, and not by surface of planet. He even assumes that in atmosphere of Venus live very many primitive organisms luminescent in darkness (apparently like glow-worms), which create observed glow of part of planet unilluminated by Sun. However, true physical state of Venus at present is still not known. It is completely possible that periods of revolution of Venus around sun and on its axes are identical. In these conditions one side of Venus will be always strongly heated, and the other frozen. For checking of true thermal conditions of this planet some scientists offer to settle it with help of rockets with special terrestrial algae, which in case of favorable temperature conditions, rapidly multiplying and being developed owing to carbon dioxide of atmosphere, after several years will transform appearance of Venus.

At present people have many tasks on native Earth. At their disposal are rich natural resources, majority of which are not used. No cosmic catastrophe threatens them. Is there therefore a necessity of emigration from Earth? Surface of Mars is unfit for habitation of people. Other places of solar system are still less favorable for their settlement. Creation on Mars according to technical formulas known to us of conditions useful for existence, is incommensurably more difficult problem than construction of above-described underground refuges. This will be difficult even in the case when with development of technology it becomes possible, using electric power from solar photoelectric batteries or nuclear reactors, to obtain oxygen necessary for breathing of people and their jet engines by means of electrolysis of silicates or other oxides, which apparently are completely sufficient also on Mars, on Moon and asteroids. It is necessary also to remember that surface area of Mars is not so big, in order essentially to expand territory occupied by people. On Earth there is still much space useful for settlement. Moreover, when necessary, there are huge areas of terrestrial oceans, which can be covered with rafts, and their construction is undoubtedly more simple than migration to Mars.

Will mining and delivery to Earth of minerals from other worlds be profitable? Apparently, with usual already mastered types of terrestrial fuels for jet engines such a measure will not have value. However, recently hypothesis was expressed that nucleui of comets consist of ice formed by very chemically active radicals of hydrocarbons. It is even assumed that grandiose explosion during fall of Tungus meteorite, which was mentioned above, was caused by the fact that not usual meteorite dropped, but nucleus of comet of ice of radicals. If such a hypothesis appears just, then substance of numerous nuclei of huge comets and oxygen obtained from cosmic oxides, is very profitable fuel for interplanetary ships.

It is not excluded that on planets of Solar system and their satellites can be found primitive plants and microorganisms very useful for terrestrial conditions. In this case it will be expedient to deliver them to Earth for mass cultivation. However some microorganisms of other worlds can be destructive for terrestrial astronauts not possessing immunity to them. Possibility of transfer of such microbes to Earth should be completely prevented. On the other hand, consequences of infection of other planets and their satellites with terrestrial plants and microorganisms still are not clear. One of such projects with respect to Venus was already mentioned above. Now not only practical, but also scientific expediency of such experiments is vague. Therefore, majority of scientists speak out for guaranteed sterilization of interplanetary ships and their equipment in initial stages of exploration of cosmos.

Interplanetary journeys are complicated by serious biological danger on the part of destructive cosmic radiations, detected recently with the help of artificial satellites and space rockets. They exist almost constantly within limits of some terrestrial radii in geomagnetic field and appear sporadically with great intensity in entire solar system. In order to protect future astronauts from them it will be necessary to construct cabins with thick armor. Such armor is necessary also for protection from numerous meteorites and micrometeorites. All this inevitably will lead to weighting of spaceships and decrease of their payload capacity.

At present there are assumptions that appearing sometimes solar radiation, which is penetrating, spreads approximately in radial directions from the sun, with which one-sided shielding will be sufficient. This also can facilitate problem of guarantee of large payload capacity of interplanetary transport.

Meaning of penetration into space -- consists first of all in knowledge of surrounding world and in particular, in familiarization with past and contemporary cosmic civilizations, if they existed and do exist. All this is necessary for more correct planning of our further life in future millenniums. Especially tempting would be intercourse with more well-developed cosmic civilizations, whose scientific and technical achievements could increase welfare of people. Apparently, these very problems also will be solved by future hero-astronauts.

History knows many courageous explorer-travellers. They sacrificed their life for achievement of goals, which in their time were not always expedient. It is quite obvious that in ensured society with huge power resources there will always be economic and technical possibilities for cosmic journeys. The matter doesn't concern the hero-astronauts; after all we talk about great and honorable problem of knowledge of surrounding world for good of humanity.

Journey within limits of Solar system with jet engines used at present can be carried out in several years. But journey on such a transport even to the nearest star system would occupy the time of life of several generations. Consequently, for humanity maximum possible speeds of cosmic transport must be mastered. At present many scientists are occupied with development of theory of so-called photon rockets. It is assumed that a photon rocket will accelerate owing to intense luminous flux to speed nearing velocity of light (i.e., million billion kilometers in year!), which is fundamental limit for all bodies. The same source will ensure also its subsequent braking. Photon rockets are now the only possible means in principle for distant interstellar navigation. Although in some fictional novels such rockets are described as something evident and practically realizable,

nonetheless the most unclear in this problem is question about source of light (photon) radiation. At present it is still impossible to affirm that such sources of energy are unrealizable, inasmuch as there is no confidence in the fact that all basic laws of nature are already known. But now they are not found among known natural resources.

Time interval between sending of travellers into far stellar worlds and their return can be so great that actual return to Earth will lose meaning, inasmuch as after millions, tens and hundreds of millions of years civilization existing on it can completely disappear. Therefore, problem of duration of civilization is exceptionally important for appraisal of limiting prospects of astronautics. According to theory of relativity, astronauts themselves will be in the most favorable conditions, inasmuch as on interstellar ship moving with speed close to light, the flow of time, and consequently also aging essentially are delayed, the more the greater the speed*. Such astronauts can succeed in seeing goal of their journey. However, they will remain at lower stage of development than inhabitants of world left by them, in which, according to the theory of relativity, movement of time is significantly faster.

In order to accomplish journey to the nearest stars, which light reaches after several decades and less, it is still possible to be limited to comparatively small speeds, at which delay of aging of astronauts will not exceed several tens of percent. However, to boundaries of space of Universe known to us and back light radiates in a time of around billion years. In order to be there and to return after ten years of life on photon rocket, already it is impossible to manage without huge speeds, at which flow of time on this rocket should be delayed one hundred million times**. During that time billion years will pass on Earth. Thus,

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*In greater detail about this see article of K. P. Stanyukovich and V. A. Bronshten, pp. 1 - 27.

**Mentioning the ten-year journey, we allowed some inaccuracy. In reality, in order to avoid dangerous overloads, astronauts will additionally race rocket to maximum speeds and then brake it, during which several years or even tens of years will be spent additionally.

information obtained with help of astronauts will be inevitably late and the more significant the greater the distance to investigated parts of Universe. The number of worlds, information about which can be obtained by contemporaries of beginning of journey is small. Their descendants will appear in more profitable conditions. However, astronauts no longer will succeed to deliver information from very great distances if time of their absence exceeds period of existence of their native civilization. For their own daring (to decide on very far cosmic journey) photon astronauts most likely will pay by the fact that they will be forced to remain living on spaceship or more to some planet useful for life.

For photon rockets an almost insuperable obstacle is their collision with interstellar gas and dust medium. Such collisions will be accomplished at speeds sufficient for different nuclear reactions. All this occurs also during interaction of terrestrial substance with very fast particles of cosmic rays. But collision of photon rocket with small meteorite will be equivalent to explosion of atomic or thermonuclear bomb. Therefore, it is considered that photon navigation will be possible only when direct collisons of rocket with interplanetary gas and dust medium can be avoided.

As example of safety device it is possible to imagine powerful source, emitting in space in front of rocket ionizing radiation, which reports all opposite particles of electrical charge. In principle all charged particles can be deflected by magnetic field created around photon rocket. However, it would be absurd now to describe the construction of such a rocket. It is possible only to affirm that because of the necessity of superpowerful sources of energy, photon interstellar ship should have huge dimensions. Astronauts will be behind thick, in any case, meter thick armor in order to protect themselves from destructive nuclear radiations. Apparently, descriptively speaking, it is better to talk no longer about spaceship, but about large planet with internal inhabitants controlling its motion. And here is something else...

Charged interstellar gas and dust particles, repulsed from magnetic field of photon rocket, will be turned into particles of cosmic rays. If we are not limited in imagination to photon rockets of very great speed, then it is possible to explain mentally all observed cosmic rays, especially of very high energies, by activity of reasonable highly civilized living creatures of cosmic space. Contemporary physicists and astrophysicists, who advanced another theory of origin of cosmic rays and found numerous proofs of their own points of view, will hardly agree with this.

After all that has been presented it is possible to touch also the question about visit to Earth by other cosmic inhabitants. All that was reported about cosmic journeys of people can completely refer also to inhabitants of other worlds. Martians (of course, if they existed) most easily of all could accomplish flight to Earth. Their journey could be accomplished on rockets analogous to those used by us. Recently the hypothesis of M. M. Agrest about visit of Earth by cosmic travellers in ancient times became known. The gist of this inference apparently is based on popular opinion that people created gods and their surroundings according to their own image and likeness. Inasmuch as in Biblical and other religious legends it is a question of guests from sky and ascension there of certain people, then consequently, the cause for such legends must be some contemporary real facts in surrounding reality.

Quite recently author of fictional novels A. Kazantsev begin to affirm that inhabitants of ancient Peru were descendants from Venus, or in any case, witnesses of visit of Earth by its inhabitants. He bases his fantasy on peculiarities of ancient Peruvian calendar, as more applicable to Venus than to Earth*. For greater likelihood of such a fantasy it was necessary to assume that on Venus after migration of its inhabitants to Earth there occurred a gigantic catastrophe, changing

*A. P. Kazantsev assumed that period of rotation of Venus on its axis is equal to ten twenty-four hour periods. However at present question about rotation of Venus remains unsolved. It is completely possible that periods of rotation of Venus on its own axis and Sun's are identical.

its appearance and physico-chemical conditions in the direction of unfitness for existence of creatures similar to us.

It is not business of physicists to check historical arguments. This is business of archeologists. For physicists and chemists substantial proofs are necessary. Inasmuch as cosmic travellers are thought of as representatives of a civilization with highly developed technology ensuring cosmic flights, then first of all it would be desirable to find at least traces of ideal materials used by them, including also synthetic ones. Such materials could resist destructive action of time. However, now such finds do not exist. There are no reasons, like M. M. Agrest and A. P. Kazantsev, to take ancient cyclopean constructions in region of Dead sea or in Peru for such relics. Technology of their manufacture and materials are most typical for Stone Age. In them, and also in scanty primitive pictures and inscriptions it is difficult to see even any hints of influence of civilization able to accomplish space flights.

Possibility of visit of Earth by outside creatures, especially with cruel intentions (as in some fictional novels) naturally should attract attention with respect to considerations of precaution. However, till now no reliable evidence of such events in past has been found and no convincing proofs of their possibility in future have been yet made.

Although we are witnesses of greatest achievements in mastering of cosmos, there is still no clarity in final prospects of journeys of people from Solar system, etc. Here fantasies are greater than real projects and technical possibilities. Isn't it simpler, therefore, at this stage of terrestrial civilization to try to detect signals sent by inhabitants of far worlds? At present the question of most expedient radio waves for such signalling already is being investigated and rich possibilities are being opened of generation of powerful very narrow beams of luminous flux sufficient for guarantee of cosmic radio communications.

People loved and love to erect grandiose monuments of culture, preserving thus information about themselves and their achievements for future generations. It is possible that other reasonable creatures living somewhere outside Earth possess the instinct of self-announcement. There is no doubt about the fact that in the presence of sufficient power resources they can ensure transmission to other stellar worlds of images with help of radiotelegraph. Such signals can be more easily deciphered than any other, as was done during transmission of images of reverse side of Moon from Soviet interplanetary station. For year can be taken several images of very high clarity, and after many years it is possible to accumulate extensive information about other worlds and their culture without direct journeys there and back. Even now in daily life people don't always resort to journeys, and successfully use movies and television to find out what exists and is accomplished far from us. In principle radio communications between isolated cosmic civilizations is completely possible.

Success of contact with other cosmic civilizations with help of astronavigation or radio communications will be more probable, the more numerous and more long-lasting these civilizations.

With help of spectral analysis the simplest organic compounds were detected on Venus, Jupiter, Saturn and in cosmic space. More vague is process of appearance of living substance. However, if we allow in primary medium of grandiose accumulation of organic radicals and molecules the formation of only one molecule of desoxyribonucleic acid or some simpler molecule which was its predecessor, then due to the ability of such formations to be multiplied and improved in process of reproduction, it is possible to assume fast intermittent process of transformation of huge masses of primary organic matter into living.

Up to appearance of reasonable creatures the possibility of life will strongly depend on favorable conditions of environment. However, as soon as such organisms appear, reliable adaptation to unfavorable situation will become possible. Therefore,

for habitation on other worlds of living reasonable creatures at present, the constant presence thereof favorable conditions is not necessary, but only their supremacy in period "childhood" of such creatures.

Just now some circumstances were mentioned in substantiation of possibilities of greater probability of appearance and longevity of reasonable life in other stellar systems. But for estimate of number of highly developed cosmic civilizations not less essential is the question about beginning of evolution of different worlds of universe. At present on this matter animated discussion is being conducted and conventional point of view does not exist. Basically it is possible to note three possibilities.

First, stars with their planets were continuously formed and are formed by the course of evolution of any stellar systems. Secondly, all stars with their planets in any numerous stellar system, for instance in galaxy, were born and are developed simultaneously. Third, even in part of universe known to us all stars with planets were engendered simultaneously and are evolving now jointly.

In case of second and third possibilities, for existence at present of civilizations, outstripping ours, i.e., such with which radio communications can be established, it is necessary that some of them were developed as compared to Earth for shorter time from beginning of appearance. Some irregularity of development probably is inevitable. However, practically in intercourse this distinction will decrease because of the delay of cosmic transport and radio signals. This delay, as already was noted, will be the greater, the more remote the civilization capable of intercourse. All information accessible for reception will correspond to its past, and not its present. Apparently, the first evolutionary possibility is the most favorable for realization of cosmic contacts, and especially in stellar systems with significant stellar density, inasmuch as between neighboring stellar systems in this case distances will be smaller.

In examining the question about contacts with extraterrestrial worlds it is impossible to manage without cosmogonic theory finally proven in details, those

appearance of course, is awaited with great impatience. However, with limited technical possibilities in initial stage of evolution of human society only in near worlds is it possible to expect civilizations easily detected and outstripping ours. Their number will be the more significant, the higher the fundamental probability of appearance of life from primary inorganic substance and the greater its longevity.

The problem of identification among thousands, millions and billions of stars of those which have planet with highly developed civilization is very complicated. However identification is necessary in order to direct to needed place narrow beam of radio waves. Here is untapped region for technicians and inventors. In order to master nature, people frequently arrive at formerly unforeseen technical solutions. It is curious that until invention of radar everyone saw bats, but on one ever noticed that they use ultrasonic location. But this characteristic of theirs was immediately noticed and recognized when radar came into daily practice of man. Maybe with growth of civilization people will learn to find inhabited worlds which now remain unnoticed.

Gaps in knowledge of universe often are compensated by conjectures, and restlessness by numerous technical projects. And although one should refer to them with great caution, nevertheless separate ones are so interesting that they cannot be bypassed in silence. Certain scientists, for instance, consider that the most reasonable means of self-announcement is shipment into cosmos of great number of small special rockets, which are supplied with tape recorder recording of necessary information, and a radio transmitter fed from light sources of electric power. This is somewhat reminiscent of emergency means of communication of naval travellers in past, when they threw into ocean bottles with notes. Such devices will function near stars. And if during this time on their planets highly developed inhabitants appear, then they simply will carry out radio reception of necessary information. In the opinion of authors, such monuments of cosmic civilizations will be more economical and accessible for detection than radio transmitters of other worlds.

Sceptics, however, can put question, what should be reliability of such cosmic stations in order to ensure efficiency during hundreds of millions and billions of years?

Another example of creation by civilizations of monuments is idea of construction and distribution into cosmos of reasonable automatic machines -- robots. I. S. Shklovskiy noted in connection with satellites of Mars that the most long-lasting monuments, not yielding to destruction by tectonic forces of planets, can be large artificial satellites, revolving on unusual cosmogonic orbits. It is possible even to try to consider as artificial monuments of formation like rings of Saturn, inasmuch as acceptable explanation of their origin still is absent. In any case, similar assumptions can serve as good stimulus for searches for other substantiated explanations of these now enigmatic phenomena of nature.

And here there is still something... Recently famous English astrophysicist Hoyle in science-fiction novel "Black Cloud" described cosmic being in dimensions commensurable with solar system. He gave it incredible force and highly developed intellectual abilities. It is possible, of course, to concoct as many such creatures as desired. And there are no doubts that appearance of new fictional novels about inhabitants of universe will continue. However, when fictional gigantic cosmic creatures are described, question involuntarily appears, why is such a practically existing, highly organized and long-lasting cosmic organism as human society eliminated? In it separate man was and will be in cosmic scale only an elementary short-lived and easily replaceable cell. Human society although already possessing rich life experience and high scientific and technical skills, still is in stage of development and improvement. It is obvious that in perspective it will be turned into mightier reasonable organism. Therefore, for reconstruction of images of other inhabitants of universe, as starting point it is best use just this practically existing and yielding to exploration already subduing cosmos of living organisms -- human society.

It even seems that this is fully substantiated. No doubt man as reasonable creature appeared as a result of complicated development of organic substances. Vital processes are result of existence of complicated organic substances. Now we still do not know any other organisms except on the basis of carbon, hydrogen, oxygen and some other known elements. But all these elements dominate even in the most remote regions of Universe, subject at present to detection. Therefore, it is possible to expect that life is developed in universe, although with peculiarities caused by local physico-chemical conditions, and also with some features general for entire universe, consisting of atoms known to us*.

Finishing cursory survey of questions posed in beginning of article, it is necessary to note that the further the imagination strays from Earth, the more indefinite become forecas s about penetration of reasonable creatures into cosmos and the riskier it is to be caught on path of groundless fantasies. In order to avoid such a danger, further perennial scientific explorations and patient awaiting of their results are necessary. However unnecessary scepticism is not better than excessive optimism. In any case, analysis of any circumstance which can shed light on questions touched here is necessary. For this it is necessary also to synthesize information from different scientific disciplines. It is necessary to solve and to generalize the most difficult problems of physics, astronomy, chemistry, biophysics and technology. How great is scope for human creative work! There is no doubt that successes in study of cosmic space will be continuously multiplied. Unlimited possibilities for them will appear when all human society, completely overpowering need and having reached high welfare, will free for this purpose huge material and intellectual resources not even imagined until now. Our daily labor, directed towards conquest of happier life, simultaneously is also the means ensuring in near future new grandiose plans of conquest of cosmos. Huge successes in all regions of people's economy create durable foundation for successful realization of these plans.

*In many fictional novels living organisms are described with as arbitrary as desired structure and manifestation of vital activity. However all this is only the fruit of fantasies, which is not open to any reliable substantiation.

# PROBLEMS OF INTERSTELLAR COMMUNICATION

G. Kokkoni and F. Morrison

Till now there are no theories which could estimate probability of possibility of formation of planets, origin of life and evolution of societies capable of scientific achievements. However, it is possible to consider established that part of stars of main sequence with age of many billions of years are surrounded by planets, on some of them there is life, and on one of such planets life reached such a level at which a society appeared, capable of definite scientific successes. Age of such a society is unknown, but probably it will compare with time of history of human society or even with geological time. This means that around many stars like the sun there are civilizations with scientific interests and technical possibilities in some cases more powerful than we have. Attention of any civilization can be attracted by our Solar system as suitable with respect to conditions for formation of new society. We can assume that many years ago they established communication channels which will become known to us, and that they persistently expect an answer to their signals, which will let them know about the fact that new society entered into communication with them.

What kind of channel for communication could be used?

## Best Communication Channel

Interstellar communication through galactic medium without losses is practically possible only with the help of electromagnetic oscillations. Since problem of those who possess source of radiation is search for appearing society, then one may assume that source utilized by them should possess high resolving power and minimum band of frequencies. Furthermore, signal does not have to be strongly weakened in interstellar medium or in atmosphere of planet. Radio waves with frequencies below 1 megacycle and higher than frequencies of molecular lines of absorption (near 30,000 megacycles), and also of gamma rays will be absorbed by atmosphere of planets. Wave length which seems physically acceptable could lie near the region of visible or gamma rays, but this requires either very powerful source of radiation, or very accomplished technology. The most rational seems use of radiorange in region of frequencies from 1 megacycle to 10,000 megacycles.

In region of radio waves source is observed on background of radiation of its own stars (we consider that angular resolution of equipment does not give possibility to separate source from star, since source will coincide within limits of resolution with star; distance less than 1") and of galactic radiation.

Let us consider the dependency of these interferences on frequency. Stars similar to calm Sun radiate flux of energy in wide interval of frequencies. On what frequency should we observe it? Search for weak signal in wide range on unknown frequency is difficult, but in radiorange there is frequency which should be known to all who study the Universe; this is the line of radiation of neutral hydrogen 1420 megacycle ($\lambda = 21$ cm). It is completely permissible to assume that sensitive receiver on this frequency can be made at early stage of development of radio astronomy. State of our terrestrial instruments indeed justifies such an assumption; therefore, we consider that one should conduct search in region of 1420 megacycle.

## Requirement for Power of Transmitter

Galactic background near line 21 cm amounts to $10^{-21.5}$ w/m$^2$· sterad· cps for 2/3 of directions in the sky. In direction of plane of galaxy it is 4 times higher. Therefore, it is most profitable to observe those near stars which are far from galactic plane. If source is round mirror, then flux required for creation in receiver of such a signal as from galactic background is equal to $10^{-24.2}R^2/l_1^2 l_2^2$ w/cps (R is distance to star, $l_1$ is the diameter of transmitting antenna, $l_2$ is the diameter of receiving antenna). For transmitter and receiver with mirror, as at English radio astronomical observatory Jodrell Bank ($l$ = 78 m), and for distance R = 10 light years, power of source should be equal to $10^{22}$ w/cps, which is on limit of our technical possibilities. But if dimension of two mirrors of telescope is such as is planned for mirror of Naval Research Laboratory in the United States ($l$ = 200 m), then source can be 40 times less powerful, which is already fully within our possibilities.

We assumed that transmitter radiates in direction of all stars similar to Sun in galactic vicinity. It is possible to add also that creation of one hundred sources of radiation of described type is not impossible for society more well-developed than ours, and we can look forward to obtain signals from stars several tens of light years away.

## Detection of Signal and Bandwidth

In all directions outside plane of galaxy radiation in line 21 cm is not observed. For stars in direction far from plane of galaxy, one should conduct searches near this wave length. However, unknown Doppler shift, which appears due to motion of invisible planets, forces us to assume that observed emission possibly has frequency more or less than natural on ± 300 kilocycle (± 100 km/sec). Nearer to galactic plane, where line 21 cm is strong, frequency of source probably lies

inside natural wings. If prolonged radiation interests us, then bandwidth will not be important. To begin with one should select normal width of receiving band in 21 cm., and time constant more than usual for radio astronomical observations.

## Nature of Signal and Possible Sources

There are no assumptions about how to find signal. We expect that signal should be modulated with frequency approximately equal to a second. Reports should be transmitted for several years, since no answer can be expected earlier than several decades. In the beginning one should repeat them. Possibly, different types of signals, will be revealed, alternated during a period of several years. For indisputable identification of artificial signals definite signal can serve, for instance sequence of prime numbers or simple arithmetical sum.

First attempts should be directed to inspection of the nearest stars. Among stars located at a distance of 15 light years, seven have luminosity and lifetime similar to our Sun. Four of them lie in direction of low background. These are $\tau$ let us $O_2$, Eridanus, $\varepsilon$ Eridanus, $\varepsilon$ Indi. All of them have southern declination. Three others — $\alpha$ Centaurus, 70 Ophiuchus and 61 Cygnus — lie near galactic plane, and therefore will be observed on strong background. There are near 100 stars possessing suitable luminosity among stars of known spectral type inside sphere with radius of 50 light years. All dwarf stars of main sequence between G0 and K2 with visual magnitude smaller than $6^m$, are candidates for examination.

Reader can consider given discussions as scientific fantasy. But we consider that these discussions are all that we know about nature of interstellar signals, and if these signals exist, then means of their detection are in our hands. It is impossible to negate huge practical and philosophical importance which interstellar communication would have. Therefore, we consider that it is necessary to try to look for signals from cosmos. It is difficult to determine probability of success, but if we do not look, chances of success will be equal to zero.

# STUDY OF INTERPLANETARY GAS AND IONOSPHERES OF PLANETS WITH THE HELP OF TRAPS OF CHARGED PARTICLES*

K. I. Gringauz

## Study of Interplanetary Gas

According to presently available presentations, ionized gas in interplanetary space exists in two forms: in the form of "stationary" gas, consisting of charged particles with thermal velocities, and in the form of solar corpuscular fluxes, representing fluxes of ionized gas moving in direction from the sun with speed near 1,000 km/sec.

According to appraisal of S. Chapman, considering stationary ionized gas in solar system as continuation of solar corona, at a distance of 1 astronomical unit from sun the concentration of free electrons (and ions) should be of the order of $10^3$ $cm^{-3}$ at a temperature of $10^{5°}$. L. Birman assumed that in solar corpuscular fluxes the concentration of free electrons (or ions) can reach $10^3$ and even $10^4$ particles in 1 $cm^3$. Assumptions were made also about existence of constant flux of charged particles emitted by sun, frequently called "solar wind", in which

*Abbreviated account of report read at XII$^{th}$ International Astronautical Congress in October, 1961 in Washington.

(according to appraisal of E. Parker) concentration of ions of the order of hundreds in 1 $cm^3$ is possible with speed of flux of $\sim$ 500 km/sec.

Study of question of states and concentration of ionized gas in interplanetary space is important for astrophysics, since it allows us to definitize physical properties of the medium in which planets of solar system move, and for geophysics, since solar corpuscular fluxes cause such essential geophysical effects as aurora polaris, geomagnetic storms and ionospheric storms, rendering significant influence on radio communications between different regions of Earth. Furthermore, this question has value also for astronautics or, more exactly for radio navigation in interplanetary space.

Really, with increase of instrument accuracy of radio navigational means, components of radio navigational errors connected with inaccurate knowledge of speed of propagation of radio waves will acquire greater and greater value.

Velocity of light in vacuum at present can be considered known with accuracy up to 0.3 km/sec, i.e., to $10^{-6}$. If the concentration of free electrons $n_e$ in region of occurrence of interplanetary ship is equal to $10^3$ $cm^{-3}$, then for all radio waves with frequencies not more than $2 \cdot 10^8$ cps the error of determination on Earth of coordinates and speed of ship with the help of radio methods, caused by difference of speed of propagation of radio waves in ionized gas and in vacuum, will be greater than error caused by inaccurate knowledge of velocity of light; if however $n_e = 10^4$ $cm^{-3}$, then what has been said will pertain to all radio waves with frequencies less than $6 \cdot 10^8$ cps (with this influence of ionosphere of planet on radio measurements is not considered).

Thus, some possible characteristics of interplanetary plasma met in the literature gave reason to fear that the influence of interplanetary ionized gas can limit accuracy of radionavigational measurements in interplanetary space.

It is possible of course to exclude the influence of ionized medium on speed of propagation of radio waves, using simultaneous measurements with the help of

radio waves of different frequencies, but this is connected with increase of weight of equipment and energy consumption on board the spaceship, and therefore is undesirable.

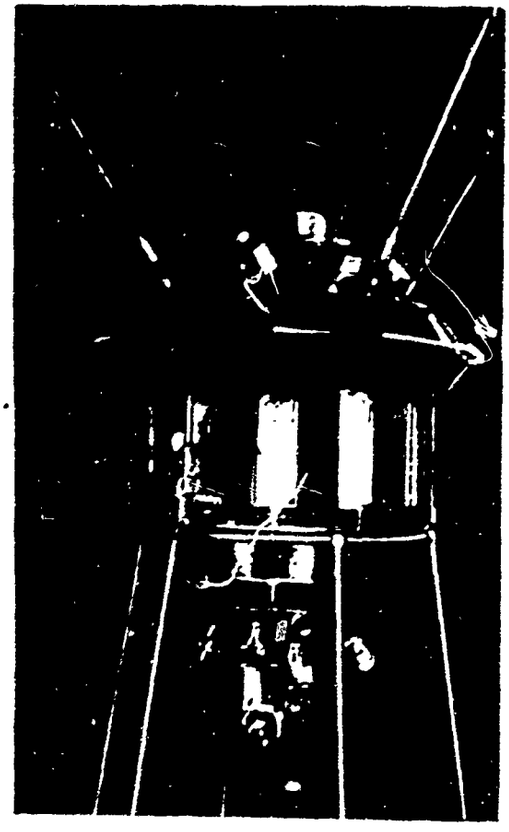

Fig. 1. Distribution of three-electrode traps on third soviet space rocket.
Trap is marked by small cross.

On all Soviet space rockets, starting with first artificial planet, launched January 2, 1959, and including automatic interplanetary station (AIS), fired in direction of Venus February 12, 1961, three-electrode traps of charged particles were established, intended for study of interplanetary plasma.

Experiments conducted with these traps allowed us to make a series of conclusions pertaining both to the possible concentration of interplanetary ionized gas with thermal velocities of particles, and also to directed fluxes of solar corpuscles.

On third Soviet space rocket, launched October 3, 1959, four three-electrode traps of charged particles were fixed. Distribution of these traps is shown in Fig. 1. Construction of all traps was identical -- it is shown in Fig. 2. On collectors of all traps identical negative potentials were given relative to body -- 30 v; on internal grids -- also identical potentials -- 200 v relative to body (for suppression of current of photoelectrons emitted from collector under action of ultraviolet solar radiation). Potentials of external grids were not identical. On external grids of two traps (on lower and on upper part of container) several times during flight for four-minute intervals of time sawtooth voltage pulses moved

with period of 20 sec., superimposed on constant voltage — 5 v relative to body, as a result of which potentials of external grids of these traps relative to body changed from +9 to —19 v. Graphs of changes of potential of external grids and collector currents of both traps during one of such intervals (in 14 hour 52 min Moscow time October 4, 1959 at R = 126,000 km from Earth) are shown in Fig. 3. For interval of time $t - t_0$ corresponding to these graphs, from rocket was transmitted altogether 240 values of voltages on external grids of traps and collector currents, the dotted line designates the absence of measured magnitudes.

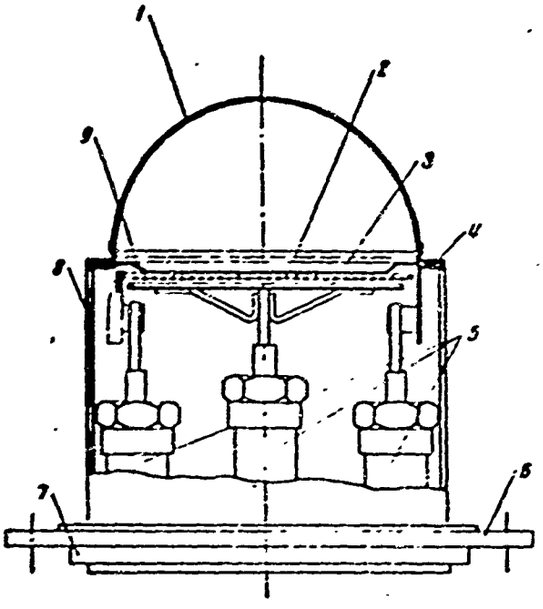


Fig. 2. Three-electrode trap. 1--External grid (nickel); 2--Internal grid (tungsten diam. 18 ); 3--Collector (nickel); 4--Isolator (teflon); 5--Hermoleads; 6--Base; 7--Consolidator (rubber); 8--Screen (aluminum); 9—Diaphragm (nickel).

On telemetric records alternate increase and decrease of positive collector currents of both traps (with period of 150 sec) is clearly visible, which reflects rotation of AMS. At the same time it is clear that change of collector currents of traps is not at all connected with change of potentials of their external grids. This apparently occurs because positive particles creating collector currents possess such high energies that changes of potentials of external grids approximately by 30 v do not influence them. If in environment there was sufficient concentration of low energy charged particles (with thermal velocities), then collector current created by them certainly would be modulated by sawtooth voltage with total amplitude near 30 v passed on to external grids of traps. Therefore, absence of similar modulation can be used for estimate of $n_i$. Such an estimate was conducted and it showed that $n_i$ does not exceed unity in cubic centimeter.

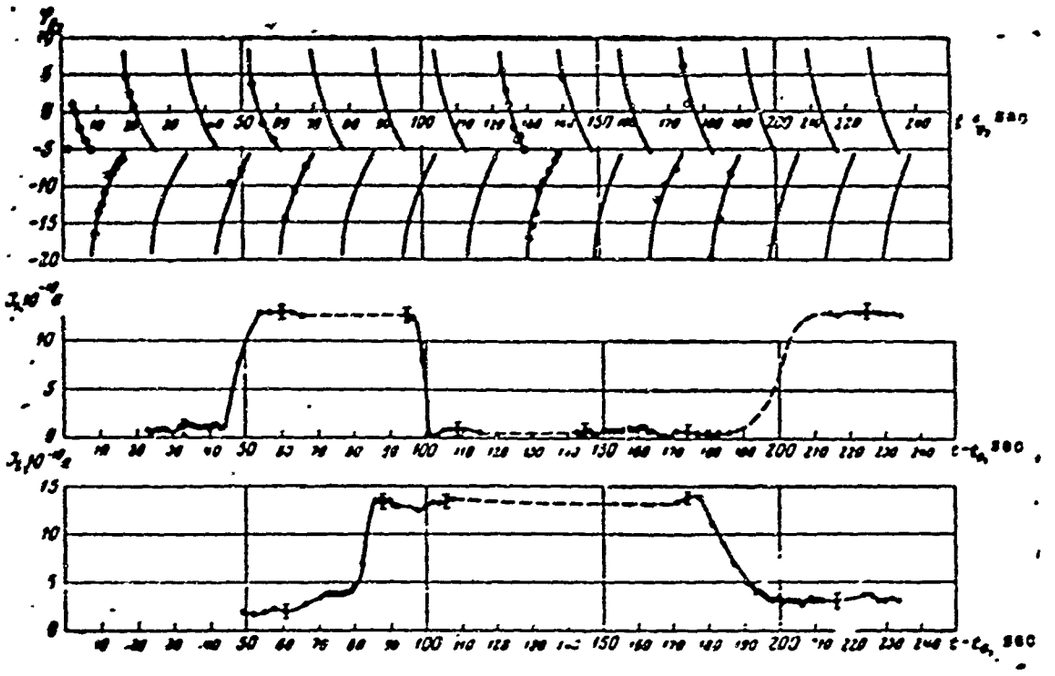

Fig. 3. Change of potential of external grids and collector currents of two traps.

The indicated minute concentration of stationary interplanetary ionized gas turned out to be unexpected and contradictory to existing earlier presentations, on the basis of which the concentration of electrons at distance of Earth from sun usually was estimated as $5 \cdot 10^2 - 10^3$ cm$^{-3}$. At the same time one should note that very recently there appeared works which confirm that the concentration of interplanetary ionized gas is minute.

From results of experiment with traps of charged particles on third Soviet space rocket it follows that free electrons of stationary interplanetary gas cannot render noticeable influence on accuracy of radio navigational measurements in interplanetary space, since their concentration is too small. Thus, the only form of existence of interplanetary plasma of interest from this point of view are solar corpuscular fluxes.

Collector currents of traps shown on graphs of Fig. 3 can be explained only by entry of AMS into flux of positively charged particles with energies significantly exceeding 200 ev, and changes of these currents by change of orientation of AMS

relative to direction of particle flux. Let us note that kinetic energy of motion of protons relative to rocket, at speed of it relative to medium of ~ 30 km/sec (equal to orbital speed of Earth), amounts to in all ~ 5 ev. Electronic component of flux does not affect the collector current, since energy of electrons of solar corpuscular fluxes is insufficient in order to overcome retarding electrical field created by internal grid of trap. Points shown in Fig. 3 correspond to flux of corpuscles $4 \cdot 10^8$ cm$^{-2}$ $\cdot$ sec$^{-1}$.

For the first time the ionic component of solar corpuscular fluxes outside the magnetic field of Earth was registered on September 13, 1959 with the help of three-electrode traps during flight of second Soviet space rocket. During flight of third space rocket in first half of October, 1959 at distances of the order of hundreds of thousands of kilometers from Earth with the help of traps of charged particles solar corpuscular fluxes were repeatedly recorded, whereupon, as a rule, good correlation between registration of corpuscular fluxes and growth of geomagnetic perturbations on Earth was observed.

Up to now the most intense corpuscular flux was registered with the help of traps of charged particles during flight of Soviet space rocket fired at Venus in February, 1961. Distribution of traps on AMS, fired at Venus is shown in Fig. .. Potentials of external grids of traps, for the first 0 v, for the second +50 v. During period of radiotelemetric communication traps were with great accuracy oriented to Sun; in connection with this registered collector currents for the first time were not modulated because of rotation of container. During period of communication starting February 17, 1961 at 1435 Moscow time, AMS was at distance of 1,890,000 km from Earth. With this for twenty-minute period in traps were registered currents corresponding to current densities of positive corpuscles $10^9$ cm$^{-2}$ $\cdot$ sec$^{-1}$.

On Earth at 12 o'clock Moscow time was registered beginning of magnetic storm. Speed of corpuscular flux, determined by time of delay of beginning of magnetic storm relative to passage of region which apparently is source of corpuscles

through central meridian of solar disk, turned out to be equal to 400 km/sec. This means that concentration of protons in flux was approximately equal to 25 $cm^{-3}$.

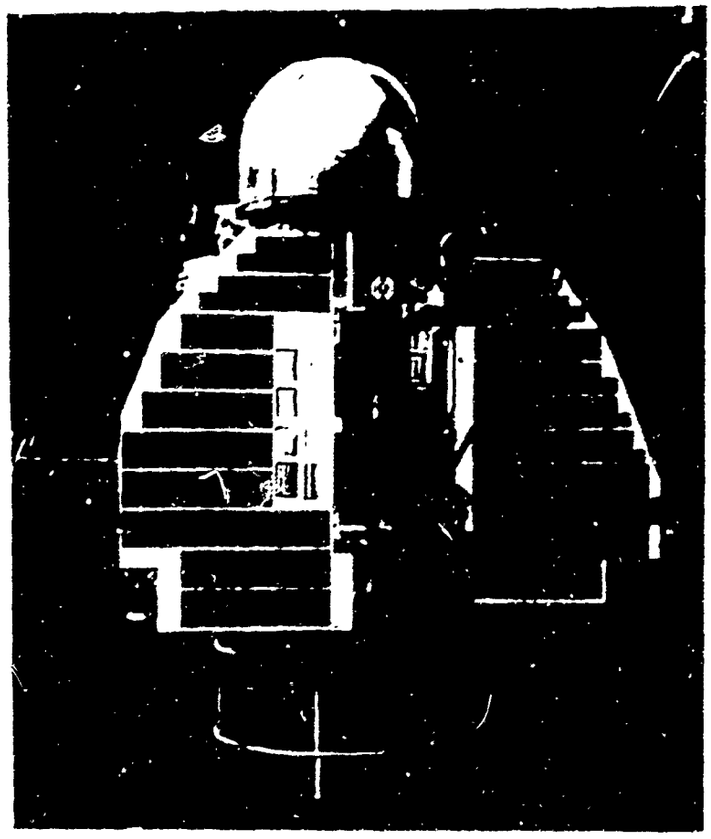

Fig. 4. Distribution of traps on AMS.
Traps are shown by pointers.

Thus, so far the few experiments conducted in interplanetary space with traps show that concentrations of charged particles in solar corpuscular fluxes can be larger than in stationary plasma.

It is necessary to note that direct observations of corpuscular fluxes outside the magnetic field of Earth can give information necessary for the establishment of numerical ratios between density of solar corpuscular flux and intensity of geomagnetic perturbations caused by it. Subsequently systematic registration of solar corpuscular fluxes in interplanetary space with the help of traps will allow us to determine the maximum concentration of charged particles in corpuscular fluxes and finally to estimate their possible influence on radio navigational errors.

At present already are being developed instruments with multielectrode traps, which will allow us to determine not only the current density of charged particles, but also their distribution in energy.

## Study of Ionospheres of Planets

From the point of view of astronautics the problem of exploration of ionospheres of planets is still more important than the problem of interplanetary plasma, since near planets the existence of significant concentrations of charged particles can be expected, strongly affecting speed of propagation of radio waves, accuracy of radio measurements, and perhaps also possibility of radio communications in certain ranges of waves. Strictly speaking, degree of accuracy of results of radar from Earth of any planet cannot be determined as long as there are no data about distribution of concentration of electrons in ionosphere of this planet.

If the chemical composition and density of atmosphere for all planets were identical, then it would be possible to estimate the maximum electron concentration of ionosphere of each planet, assuming that only source of ionization is ultraviolet radiation of sun. In this case it turned out that the concentration of electrons in ionosphere of Venus is approximately two times greater than in ionosphere of Earth (in accordance with its distance from sun), in ionosphere of Mars — approximately two times less than for Earth, and so forth. In reality however, similar estimates can't be used, since atmosphere of each planet in chemical composition and structure differs from atmospheres of other planets. Magnetic fields of different planets also differ from each other apparently as is known, the magnetic field essentially affects picture of distribution of charged particles around planet. Question about ionosphere of Venus is vague. In the opinion of Soviet astronomer N. A. Kozyrev, founded on study of spectrum of ashen glow of Venus, the concentration of electrons in ionosphere of Venus is significantly larger than in ionosphere of Earth. It is necessary, however, to note that experiment of Kozyrev is not yet

confirmed by other observations. Splashes of radio emission of Jupiter in decameter and decimeter ranges can be explained by presence there of dense ionosphere and very strong magnetic field. All this shows that study of ionospheres of planets should occupy one of first places in complex of scientific problems which must be solved before landing of people on other planets, since reliable radio communications between planet and Earth is one of the most important conditions of safety of similar expedition.

During preparation of experiments on study of ionospheres of planets of solar system it is absolutely natural to present their structure in some degree as similar to structure of ionosphere of Earth and to consider methods of studies similar to those used on Earth.

In Fig. 5 is presented tentative distribution curve with respect to height of charged particles in ionized gas blanket of Earth. Curve is plotted according to experiments conducted in daytime in 1958 - 1959 with the help of Soviet geophysical rockets, third satellite and Soviet space rockets, and characterizes period close to maximum of solar activity. Part of curve pertaining to heights 470 - 1,000 km is plotted according to experiments with spherical ion traps, established on third Soviet satellite; part of curve pertaining to heights 1400 - 20,000 km, -- according to experiments with three-electrode traps of charged particles, conducted on space rockets. On graph near row of points are shown dates of corresponding measurements. Dotted line corresponds to the absence of measurements. Mass spectrometric measurements on third satellite showed that to height of 1,000 km the ionosphere consists basically of ions of atomic oxygen.

High-altitude movement of concentration of charged particles shown in Fig. 5 to heights of 15,000 km is easily explained if in interval of heights 1,000 - 1,500 km in ionosphere ions of hydrogen start to predominate. Increase of negative vertical gradients of concentration of charged particles with respect to height, starting from height near 15,000 km, still needs theoretical explanation.

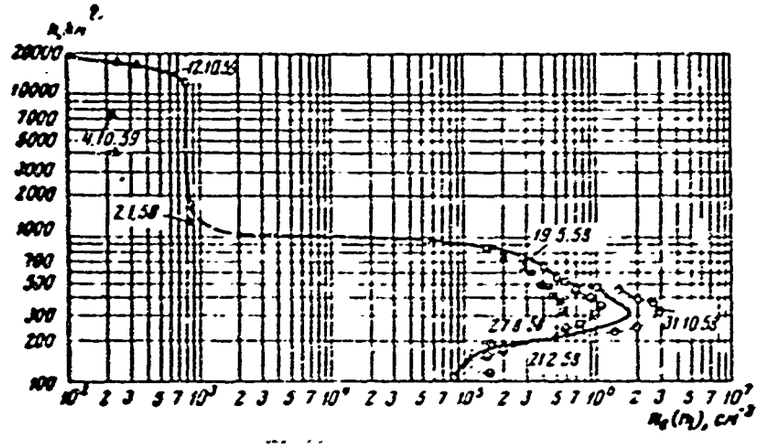


Fig. 5. Distribution with respect to height of charged particles in ionized gas blanket of the Earth in period close to maximum of solar activity.

It is expedient to note that with the help of the same three-electrode traps on first Soviet space rockets, which allowed us to obtain upper part of graph (shown in Fig. 5), there was revealed the existence of electron streams with energies more than 200 ev with density of the order of $10^8 cm^{-2} sec^{-1}$ at distances of 55,000 - 75,000 km from surface of Earth (in equatorial plane), i.e., beyond the borders of radiation belts. This gave basis for assumption about existence of the most external belt of charged particles, surrounding the Earth, with boundaries passing along lines of force of geomagnetic field, consisting of particles with energies less than in radiation belts (Fig. 6). Comparison of data of current ring calculated by American scientists (Sonnet and others) according to results of measurements of magnetic field on space rocket "Pioneer-5" with earlier published data of experiments with three-electrode traps on Soviet space rockets showed that calculated current ring and electron streams observed in our experiments are located in the same region of space and that both experiments mutually confirm and supplement one another. Concentration of free electrons in the most external belt of charged particles surrounding Earth is too small to affect propagation of radio waves in a noticeable manner. However, apparently there are no reasons to affirm the same with respect to similar belts possibly existing around other planets.

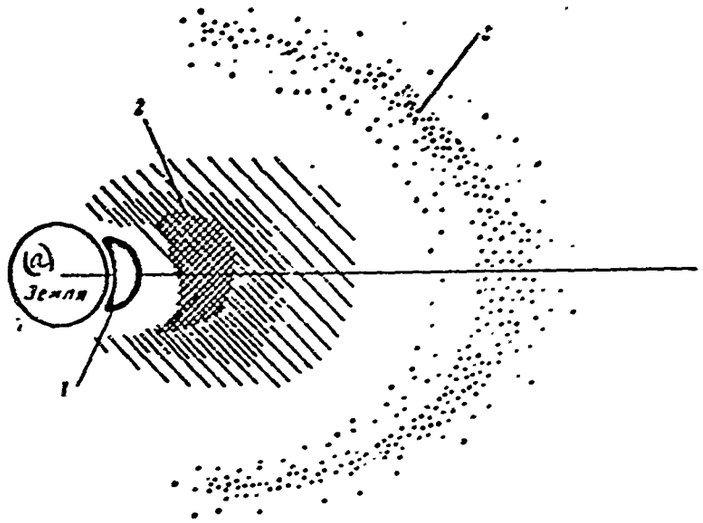


Fig. 6. Configuration of belts of charged particles surrounding Earth.
1—Internal radiation belt; 2—External radiation belt; 3—The most external belt of charged particles.
KEY: (a) Earth.

It seems to us that important data about ionospheres of planets, characterizing general content of electrons in vertical pole of ionosphere of planet can be obtained with help of simultaneous radar of planet from Earth on different frequencies. However, in such a way it is impossible to obtain information about distribution of concentration of charged particles with respect to height and about maximum concentration of electrons in ionosphere of planet, having decisive value for radio communications with Earth of astronauts debarked on planet.

Since there are no doubts about the fact that landing of people on planet will be preceded by flights to planets of rockets with automatic equipment, then equipment should be created for study of high-altitude distribution of concentrations of charged particles near the planet with the help of such reconnaissance rockets.

Such equipment can be, for instance, a pulse ionospheric station, delivered on rocket to investigated planet at sufficiently close distance; results of its measurements have to be transmitted to Earth through radiotelemetry. This method is connected with significant difficulties — the station should have very wide range of wave lengths (since critical frequencies of studied ionosphere are unknown),

and this means that receiving-transmitting equipment will have great weight. Concerning weight of station intended for study from comparatively low height of upper terrestrial ionosphere, it is possible to judge by Canadian project of artificial satellite, which will weigh more than 100 kilograms. Dispatch to studied planet of still heavier ionospheric station, which would possess characteristics necessary for study of ionosphere whose properties are unknown, in near future could significantly limit the possibility of simultaneous carrying out of other scientific investigations on the same rocket.

At the same time installation on automated research rocket sent to any planet of equipment for exploration of ionosphere of planet by probe method (for instance, of type of spherical ion traps of third satellite, three-electrode traps used on space rockets, or any of their modifications) will allow us easily to carry out measurements during passage of rocket through ionosphere of planet with as large as desired range of concentrations of charged particles (limitations will be put only on possibility of passage of radio waves of telemetric system through studied ionosphere) and with insignificant weight of equipment. Such measurements can be fully combined with whole complex of other physical investigations. Therefore, one may assume that traps of charged particles are the most important means of study of ionospheres of planets of Solar system with the help of rockets.

In conclusion one should pause still on one important possibility of application of traps of charged particles in astronautics. During entrance of interplanetary ship into atmosphere of planet correct orientation of ship relative to its vector of speed is very significant. Since ionization current in nonspherical traps essentially depends on their orientation relative to inflowing ion stream, then from moment of entrance into ionosphere traps can be used as transducers of orientation relative to vector of speed of ship.

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